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THE GEORGE W. WOODRUFF SCHOOL OF
MECHANICAL ENGINEERING

Me 4182
Mechanical Design Engineering

Nasa/University
Advanced Design Program

Lunar Bulk
Material Transport

December 1987

William L. Jones
Andrew McHenry
Earl Smith
Erik Green

Georgia Institute of Technology
Atlanta, Georgia 30332-0405

Lunar Bulk Material Transport

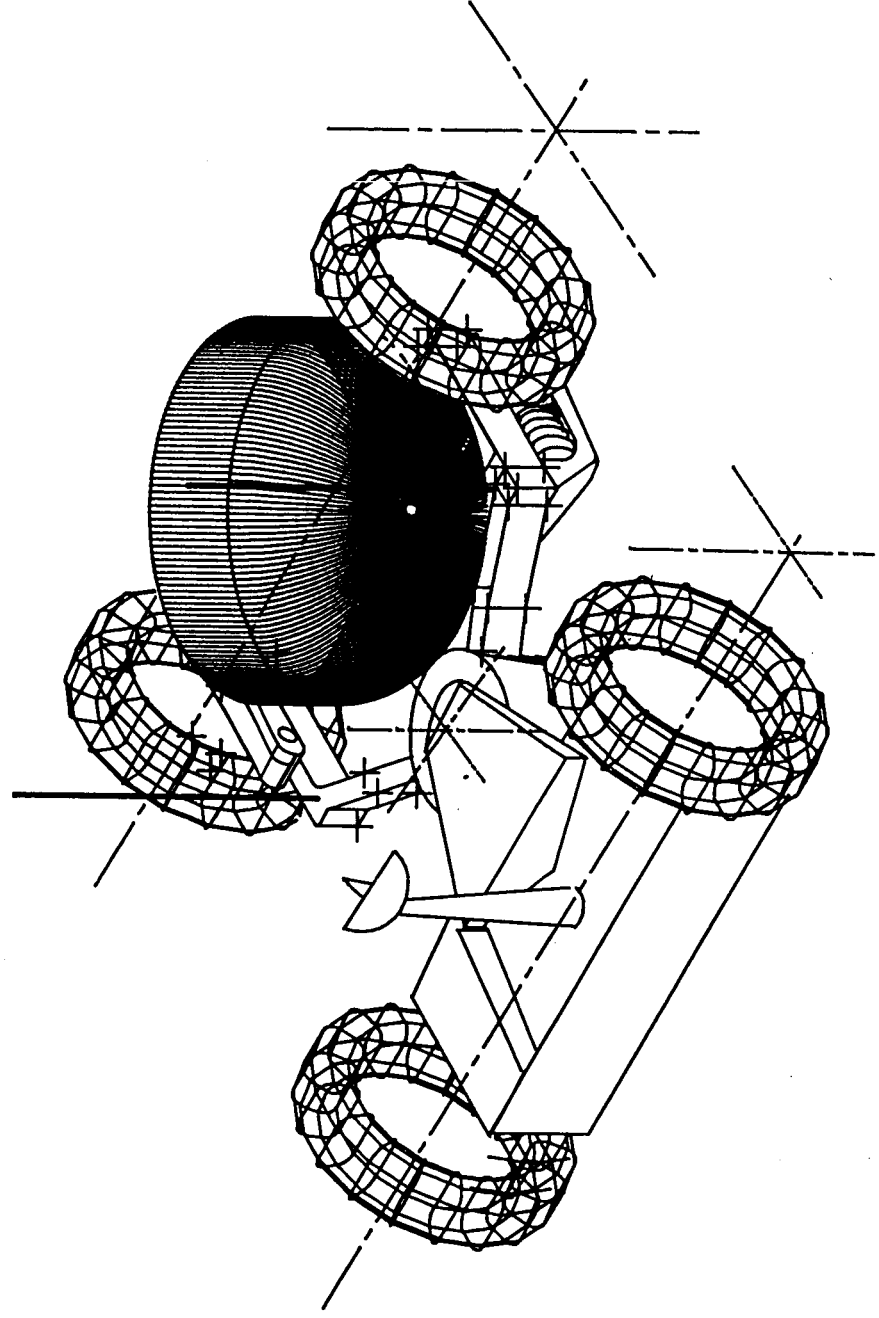


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Lunar Bulk Material Transport

Abstract

A lunar base, like any construction site, will require a dump truck. It must be light, durable, strong, and reliable.

The proposed dump truck, the Lunar Bulk Material Transport (LBMT), has been designed to meet required performance characteristics while following given constraints.

The LBMT is a four wheeled vehicle with a lift and rotate dump mechanism. The dump mechanism employs a slider-crank which is driven by a power screw. The wheels are the mesh type used on the Lunar Rover. They are directly driven by a new type of AC electric motor. Energy to power all electric components is provided by fuel cells. Articulated steering is used for maneuvering the vehicle. The LBMT will be controlled by a microprocessor based control system, but will have tele-operator override.

Problem Statement

Background

It is not unreasonable in this day and age to imagine a permanent lunar colony. However, this is not an ordinary construction project. The lunar environment places many constraints on any type of system to be used there. In addition, several factors make it undesirable to use people to operate the equipment to construct such a base. The LBMT's main function will be the transport of lunar "fill" from an excavation site to another, such as a processing facility. Thus in order to be useful to a lunar mission, it will need to meet certain performance objectives and constraints.

Performance Objectives

One piece of equipment that is common at any construction site is the dump truck. For a lunar version, some of the factors that must be considered are:

1. Reliability- Since it will be impossible, or nearly impossible, to repair the vehicle, it should be as reliable as possible.
2. Weight- The weight of the vehicle should be as low as possible because the cost of getting it there is related to how much it weighs and not on the physical size of the truck.
3. Power- The power that the vehicle requires should be as low as possible, not only to reduce the weight, but also to allow a longer period between required servicings.
4. Control- To be effective, the vehicle should have a fairly powerful microprocessor on board that is capable of controlling all phases of the vehicle operation. This processor should also be capable of responding to commands from a local controller (another microprocessor), or as a last resort, to on-line commands.

5. **Dumping-** The dumping mechanism must be able to rotate the bucket through an angle of 110 degrees in order to satisfactorily dump its contents. During travel, the bucket should remain as low to the ground as possible so as to lower the vehicles center of gravity.
6. **Speed-** It is preferred that the vehicle travel at or near 5 mph, however it will have an upper range of 10 mph.
7. **Range-** The range it will cover is 15 - 20 miles.
8. **Grade-** It should be able to handle a grade up to 20 degrees. This was determined through results of the Lunar Rover.

Constraints

1. **Size-** Anything that is to be used on the moon must first be transported there. Since the shuttle will be used for this purpose, the vehicle will have to have an upper limit on its physical dimensions.
2. **Bucket-** The shape of the bucket is fixed as a bowl shape, and it is assumed that no cuts, doors or other modifications can be made to it.
3. **Wheels-** The diameter and width of the wheels are fixed relative to the size of the bowl. For example, if the bowl is 4 feet in diameter, then the wheels will be 6 feet in diameter and 1.5 feet wide.
4. **Temperature-** It must be capable of withstanding the temperature extremes of an entire lunar cycle. Specifically, it should be able to handle a range from -120 deg. to + 120 deg.

Description of LBMT

General Layout of Vehicle

The vehicle uses an articulated steering system, and so the chassis is divided into two frames. The front chassis houses the power generation and fuel storage section. Also in the front is the control section which houses the microprocessor that controls the vehicle. Into this section lead the wires which carry control information from every controlled component of the system. These components in the rear section of the vehicle send their control signals through wires that come together in a bundle that passes over the steering pivot. The rear chassis is essentially a tuning fork shaped frame to which the dumping mechanism and rear wheels are attached. The bucket is attached to the innermost bars of the dumping mechanism. The mechanism is actually a pair of linkages, one on each side. The linkage consist of a two bar slider-crank linkage used to lift and rotate the bucket to dump its contents. The dump mechanism is actuated by enclosed power-screws that are attached to the sliders. Once initiated, the bucket is simultaneously lifted and rotated 110 degrees. The control system is a microprocessor capable of making limited judgements about the terrain, using touch sensors and a small radar. This system would accept commands from either the local controller or be controlled directly through an override system, thus allowing somewhat autonomous operation while still allowing direct control by a person if necessary.

Power

Several options for power sources would appear to be available to the average observer, but due to the nature of the lunar environment, many of these possibilities are not feasible nor practical for use on the LBMT. Initial power sources were conventional storage cells, solar arrays, nuclear reactor, and fuel cells. Conventional storage cells, such as batteries, were ruled out because its electrode life was too short in comparison to a fuel cell's electrode and so had to be replenished more frequently. Solar energy limits operation of the vehicle to lunar days and, in order to satisfy energy demands, an extremely large structure relative to the size of the vehicle would have to be

built. Nuclear energy is not feasible due to its weight and the cost of transportation to the moon. The final selection for power was fuel cells. Fuel cells main advantages are its longer operating times between refueling (as compared to conventional cells), a higher output power per weight and volume, and that it uses conventional fuels, such as Hydrogen and Oxygen, which are available on the moon's surface, and its only main by-product is water.

Motors and Power Transmission

The LBMT is equipped with four motors each driving one of the 4 wheels. The curvilinear synchronous motor was chosen over a linear synchronous motor, DC series wound motor, or a DC brushless motor. It has the advantage of having an efficiency over 90%. The curvilinear motor has the added plus of operating at up to 25 rpm and high torque. 2000 ft-lb of torque per wheel will be needed for ascending inclines up to 20 degrees. The high torque output of the motor, coupled with the ability to control the rpm, results in no necessary gearing. This is beneficial since gearing would require lubrication, a pressurized nitrogen atmosphere, and added controls. Since the motor operates at low rpm, there are no significant gyroscopic effects. Because the motor is separate from the wheel, the motor can be scaled up to produce more torque if necessary. It can be powered by DC fuel cells linked to a controller (see appendix).

Dumping Mechanism

The dumping mechanism is actually a pair of slider-crank type mechanisms, one on each side of the bucket. The slider part of the mechanism is an electric motor enclosed in a metal bellows that uses a power screw as its shaft. The screw itself is fixed to the frame, so when power is applied to the motor, it travels backwards due to the screw action. This particular part of the vehicle was probably the hardest part of the project for the design team to agree upon because of the number of other possible methods proposed. However, since this mechanism fulfilled the requirements of having the bucket as low as possible during travel, and also met the requirement of 110 degree ro-

tation of the bucket, it was chosen over the others because both of these are met by the same device. The other methods that were proposed are:

1. A method by which the entire vehicle rolled over. This method required eight wheels, and accomplished the dumping of the bucket (firmly attached to an "X" frame) by extending a section of the X frame. and thus allowing a set of wheels to climb up a rear set until the vehicle rolled onto a set of wheels that was simultaneously climbing down the front set.
2. A design that had the bucket high enough to allow the bucket to be dumped by simple rotation. This design was determined to have too high a center of gravity for the travel mode and was rejected for that reason.
3. Several standard methods such as hydraulic lifters. These were rejected because of the necessity of sealing the cylinders against the vacuum of space.
4. A gravity dump was proposed, but was rejected for the same reason as the design that had the bucket higher than the center of gravity. Also, since most metals become brittle in a cold environment, this design was susceptible to brittle fracture of the structure.

Steering Mechanism

The vehicle itself is an articulated machine, steered by pivoting the front section (or frontbox) about an axis that is between the front section and the dump. (see figure 1) At this pivot point, an electric motor is mounted with its shaft oriented vertically. On this shaft is a drum, which has a series of cables wrapped around it. These cables begin at one side of the frontbox, loop around the drum, and end at the other side of the frontbox. When the motor turns the drum, the cable feeds from one side while retracting on the other, thus turning the frontbox in the desired direction. The steering assembly is mounted on a short horizontal shaft that connects the front and rear chassis. This shaft allows the two frames to rotate with respect to each other eliminating the need for an elaborate suspension system. The assembly operates in a manner similar to a universal joint. However, the range of rotation around the horizontal shaft must be limited to small rotations so that the vehicle does not collapse while turning.

Wheels

The final selection of wheels for the LBMT were open mesh wheels. Their already proven design (as used in the Apollo mission) was an obvious choice for our application, and wheels of this kind have already been designed to allow for a capacity of up to two thousand pounds. Due to the nature of its construction, mesh wheels also allow for enough deflection that for our application (namely low speed) would not necessitate a suspension. Several other wheel designs were considered including closed mesh wheels and metal hoop type wheels. Metal hoop type wheels were used in the Soviet Lunokhod 1 mission and employed stacked, flexible cylinders. Closed mesh wheels are similar to open mesh wheels but are covered by cloth like material. Reliability of this type wheel was decreased due to rips in this outer material.

Braking

Braking will be achieved through regenerative braking. Regenerative braking simply takes the motor and turns it into a generator. A load on the generator (such as recharging the fuel cells) causes the vehicle to slow down. The curvilinear motor is well suited for this. To change the motor to a generator, the control circuitry is simply switched.

Analysis of LBMT

Motors

THE CURVILINEAR SYNCHRONOUS MOTOR (see figure 4)

The curvilinear synchronous motor, as modeled by Dr. Davey at Georgia Tech, needs certain changes for use on the LBMT. It will need to be changed from an open design to a sealed assembly. This is so that the abrasive lunar dust will have minimal effects on the moving parts of the motor. In addition, having the motor sealed will shield the brittle magnets from impacts by moon rocks.

Originally, we planned to use aluminum alloy for the construction of the motor. This was quickly discarded since the motor parts had to have magnetic properties. Lubrication needs involve only the two bearings on the shaft of the motor. The working model of the curvilinear motor has shown that it is very reliable. With design modifications, its weight can be considerably reduced. Heat generated by the motor will be radiated to the stator from which it will be conducted to the vehicle frame through the connection between the frame and stator. The curvilinear synchronous motor offers the advantage of being brushless which eliminates any problem of the brushes being contaminated by oil from the thrust bearings. Since the motor operates at up to 25 rpm, there are only minimal centrifugal stresses. The major costs involved in building this motor are the cost of the magnets, aluminum, fabrication, and labor. These costs become negligible when compared to the cost of transporting it to the moon.

The existing model of the curvilinear motor as designed by Dr. Davey has the following characteristics:

torque = 30 ft-lb. @ 25 RPM

weight = 100 lbs. for a 10" radius motor

power consumption - 12 volts x 30 amps

The torque is proportional to the radius squared. Also, the torque is proportional to the amperage into the motor. These figures must be used only to prove the effectiveness of the motor concept. The redesigned motor may show different values. It has not been constructed yet.

Dumping Mechanism

Because the bucket has a round shape, it was immediately recognized that it had to be turned at least 110 degrees to dump its entire contents. In addition to this, the bucket also has to be lifted 1.25 feet so that it does not hit the ground during the dumping movement. Another reason why this method was chosen over other possibilities is because the joints themselves can be replaced by

torsion bar, or bar springs, that have the advantage of eliminating the necessity of lubrication, and also allows the joints to be preloaded in the dump direction. This preload is desired because it would reduce the power requirements of the dump mechanism. With this information the length of the bucket arm of the linkage can be determined, and it turns out to be 1.33 feet. As for the coupler link, the angle between the coupler and the driven link should be greater than 45 degrees if binding of the joints is to be prevented (1). For the other end it was decided that it should not extend past the front of the frame. This effectively fixed the length of the coupler arm to 5.324 feet. The next thing to do was to approximate the required size of the members. The way this was done was to find the angles that the members would have to support the most load (see figures 2 and 3). This was done at the beginning position, the end position, and a few positions in between. This position of maximum load turns out to be at the very beginning of the dump cycle. Using this value, and assuming that the coupler and bucket links are essentially columns. Using Eulers formula, assuming pinned-pinned ends, and allowing for a factor of safety of 2, the critical load for a column is; $P_{cr} = 2(\text{load}) = 2(14928.215 \text{ lbs}) = 29856.43 \text{ lbs}$ This value is then inserted into Euler's formula, and the resulting equation solved for the moment of inertia I, which is then solved for the required diameter of a round bar to support the load. (3). This gives a value for the diameter of an aluminum bar of 1.2 inches. As for the power that the dumping mechanism will require, it too can be found from the maximum load on the bar First the speed at which the power screw (or slider) will move must be specified. With a value of .078 feet per second (30 seconds for the full travel of the dump) the power that the dump will need to accomplish its task under the given load can be calculated by noting that the power is just the force times the speed that it travels (2).

Using this assumption the power that the dump will need is; $P = (2)(14928.2 \text{ lbs})(.078 \text{ feet/sec})$
 $= 2,165.46 \text{ lbs ft/sec.}$

Fuel

Since this design utilizes several components that are part of a currently developing technology, the exact power requirements of the vehicle are not known. However, for fuel cells the amount of power that can be generated can be found from the reaction of hydrogen and oxygen. the chemical

equation is; $H_2 + 1/2O_2 \rightarrow H_2O$ The electrical energy generated by this reaction is 200 kJ per mole of H_2 and this reaction generates 86 KJ of heat (4). For the dump mechanism, the power that it will require is about 3 J of energy per second. this works out to .015 moles of hydrogen and .0075 moles of oxygen per second. The entire motion Takes about 30 seconds, Translating into 0.225 moles of oxygen and 0.45 moles of hydrogen. This is approximately 7.65 Kg of fuel to power the dump (this is an approximation because it does not include lowering the dump). As for the power needed to drive the motors, Since they are a new technology the power requirements are not known.

Wheels

Conclusions

The Lunar Bulk Material Transporter operates in an extremely harsh environment. Temperatures in the lunar cycle vary from -120 to 120 degrees ,no atmosphere exists on the moon, traction is 1/6 of that on earth whereas inertia remains the same as on earth, the exact nature and behavior of the lunar soil has not been tested yet, and the distance from the earth to the moon poses a communication delay of several seconds. The vehicle designed has addressed many of the above problems, and solutions to them have been proposed in this report. The vehicle will be use an articulated steering powered by its own motor. Each of the wheels will be driven by its own motor.

A two bar slider-crank will dump the contents of the bucket while rotating it through 110 degrees. Power to the entire system will be provided by a fuel cell arrangement. Control will take place through a microprocessor by an external operator. Although only in its initial design stage, the proposed setup of the vehicle will meet the performance objectives and constraints.

Recommendations

This design provides a stepping stone for further inquiry into the feasibility of building a dump truck for the moon. In order to continue the design we recommend that an in depth study be conducted on several systems of the vehicle.

1. Curvilinear Motors- this concept as developed by Dr. Davey at Georgia Tech, was beyond the scope of this class. It is recommended that the performance characteristics of these motors be studied at various sizes, and that some lightweight design of the motor's structure be developed.
2. Chassis and Steering mechanism- it is recommended that a structural analysis of the chassis be done. The steering mechanism's pivot point needs to be designed in detail giving it the two degrees of freedom as required for the articulated steering design.
3. Wheels- Further research into the actual structural design of the wheels must be accomplished. The extremely high density of lunar soil will require the wheels to handle up to 2000 lbs each (this weight corresponds approximately to the largest possible design of the dump vehicle - in moon pounds).
4. Fuel Cells- information needs to be gathered on the exact fuel cell(s) to be used for this particular application. A Hydrogen/Oxygen fuel cell appears to be the choice at this time, but future technology may provide a more efficient and smaller unit. Since it is envisioned that the vehicle will provide many hours of service, we recommend that a reliable and save way of re-fueling the fuel cells also be developed.

Acknowledgements

1. Dr. Kent Davey PhD.- EE dept. at Ga. Tech- provided vast information on his curvilinear synchronous motor.
2. Dr. Melbourne F. Giberson PhD.- provided info on chassis shape.

3. Mr. David Ross- VA Hospital Rehab. Research Center- provided control diagrams for the curvilinear synchronous motor.
4. Mr. James Brazell- provided numerous hours of guidance.

References

Shigley, Joseph Edward and John Joseph Uicker Jr., "Theory of Machines and Mechanisms", McGraw Hill Inc., 1980. Cannon, Robert H., "Dynamics of Physical Systems", McGraw Hill Inc., 1967. Shigley, John Joseph and Larry D. Mitchell, "Mechanical Engineering Design" McGraw Hill Inc., 1983. Masterton, William L., "Chemical Principles", W. B. Saunders Company, 4th Edition, 1977. Ogata, Katsuhiko, "modern Control Engineering"; Prentice Hall Inc., Englewood Cliffs N.J., 1970. Dieter, George E., "Engineering Design-A Materials Processing Approach", McGraw Hill Inc., 1983. Beakley, George C., Leach, H. W. and Kendrick, J Karl, "Engineering- An Introduction to a Creative Profession"; MacMillan, New York, N.Y. 1977. McGill David J., and King, Wilton W., "an Introduction to Dynamics"; Brook/Cole Engineering Division, Monterey Ca., 1984. Fitzgerald, A.E., Higgenbottom, David E., and Grabel, Arvin "Basic Electrical Engineering"; McGraw Hill Co. 1981. Spotts, M. F., "Design of Machine Elements"; Prentice Hall Inc., 1961. Tipler, Paul A., "Physics"; Worth Pub. New York, N.Y. 1976.

Appendices

Control System for the Curvilinear Synchronous Motor

On the pages that follow, the control system is shown for the curvilinear synchronous motor. Although the motors used on the LBMT will be of different design than the existing prototype, they will require the same control scheme.

The 6809 processor, (p.B), drives the programmable timers (p.D). The bottom timer outputs a square wave with a frequency of 16 kHz. The signal travels to the upper timer which updates the pulse width.

The output from the upper timer then enters the LSM Power Module Interface (p.E). The 12v modules output the signal through 6 optical isolators and then enters the 6 MOSFETs, which are all driven by the upper timer. The signal output then drives each of two MOSFETs, (p.F), one for the positive side of the motor and one for the negative side. These power the motor. Since it is a three phase motor, it requires three sets of LSM Power Modules, one per phase. Lastly, the Interface Adapter, (p.G) provides feedback into the processor and tells the control where the motor is by using an optical sensor.

THE DUMP MECHANISM

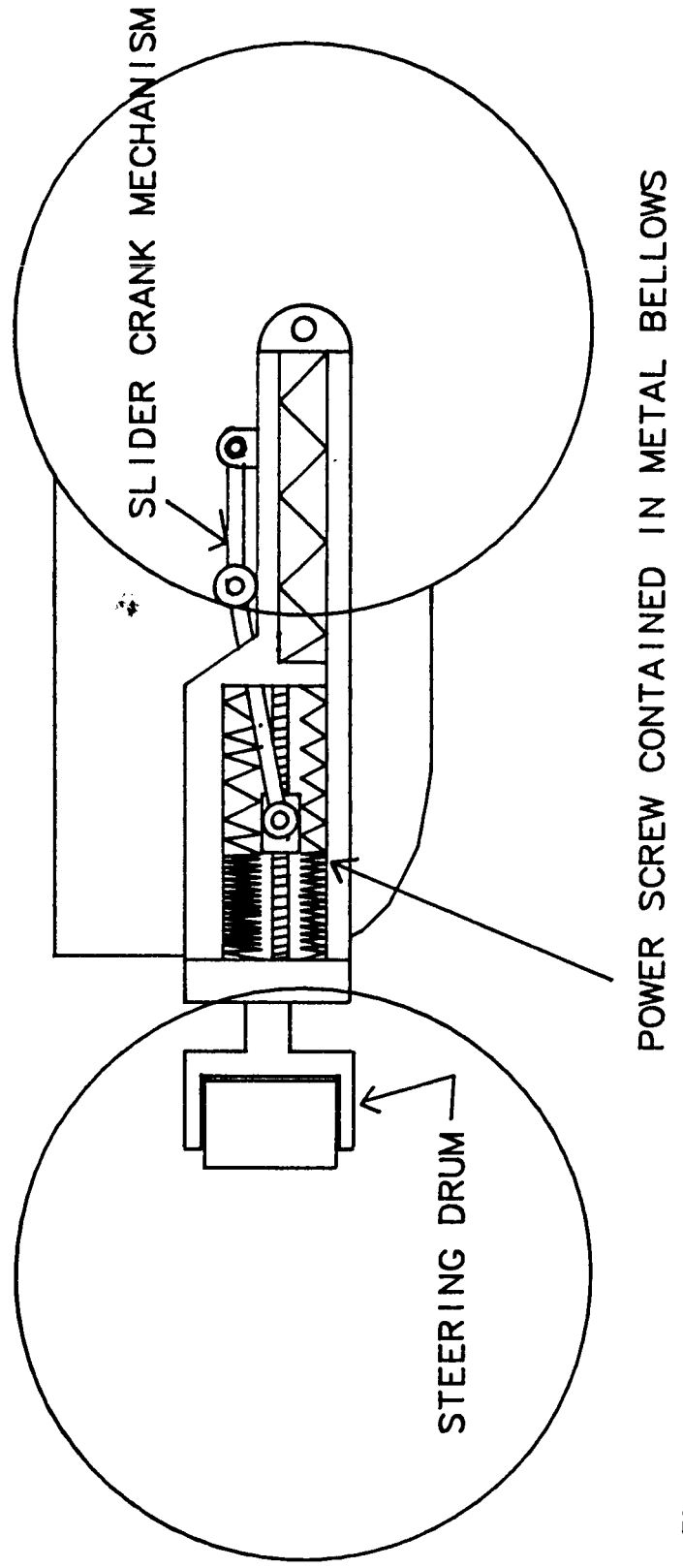
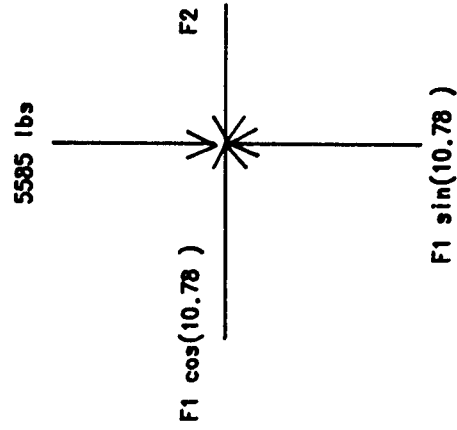
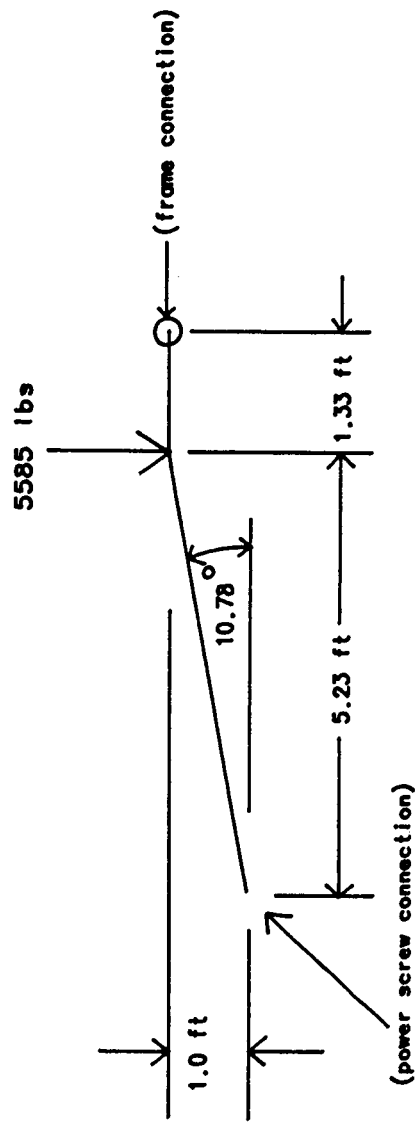


Figure 1



$$\sum F=0: F1 \sin(10.78) = 5585 \text{ lbs}$$

$$F1 = 29860.17 \text{ lbs}$$

$$F2 = F1 \cos(10.78) = 29,333.22 \text{ lbs}$$

LINK FORCES AT BEGINNING OF DUMPING MOTION

$$(\text{Moon Weight} = \text{Earth Weight}(33506 \text{ lbs})/6)$$

Figure 2.

FORCES ON LINKS AT 5 DEGREE INCREASE IN BUCKET LINK ANGLE

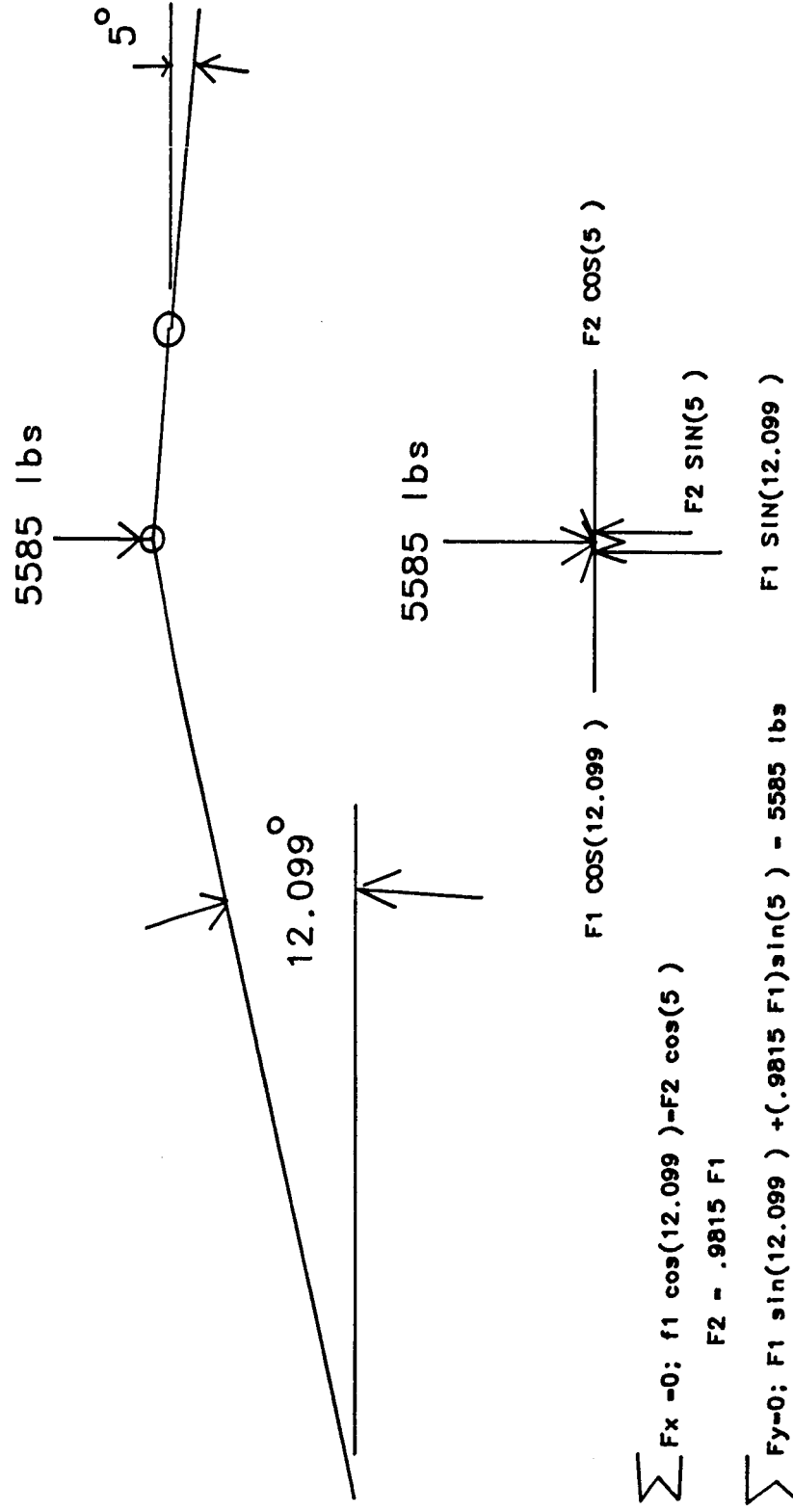
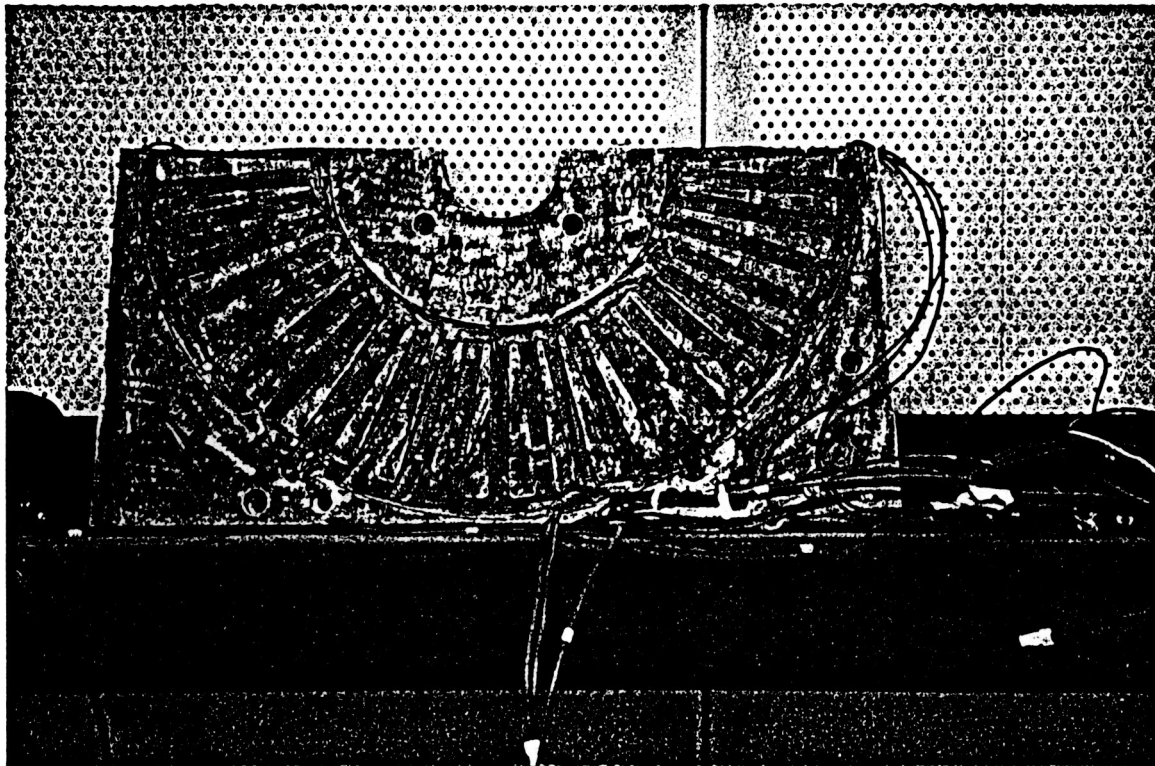
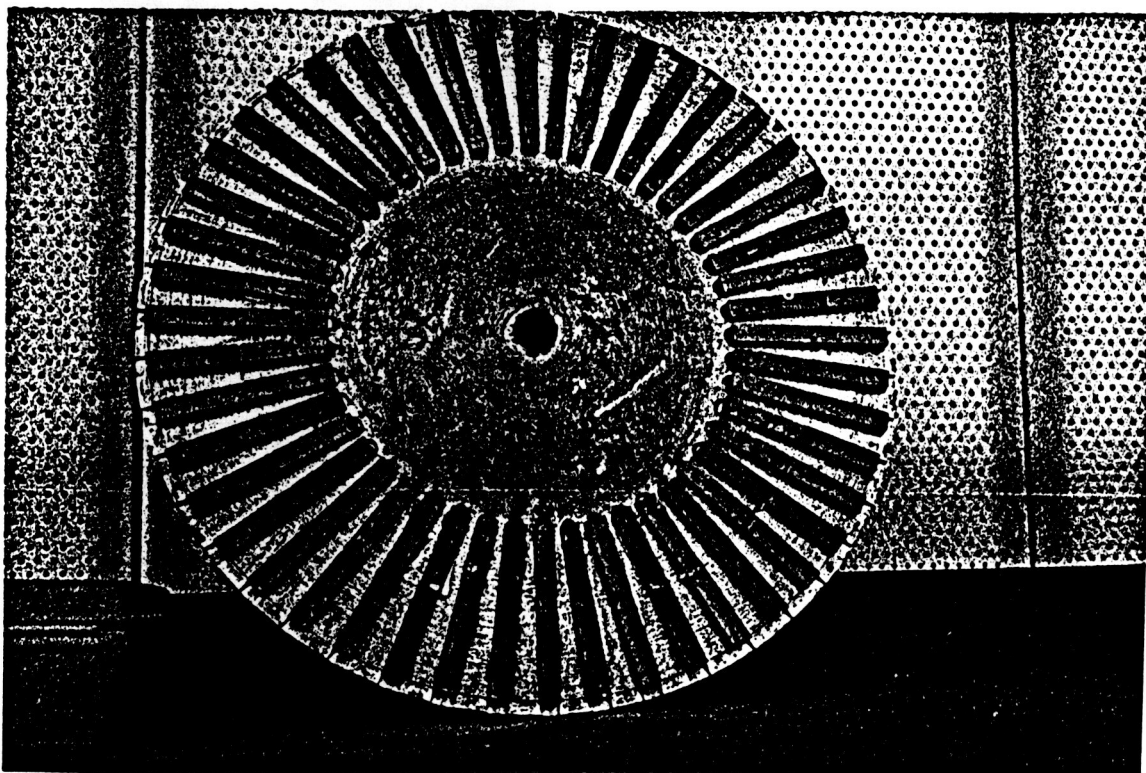


Figure 3

Curvilinear Synchronous Motor

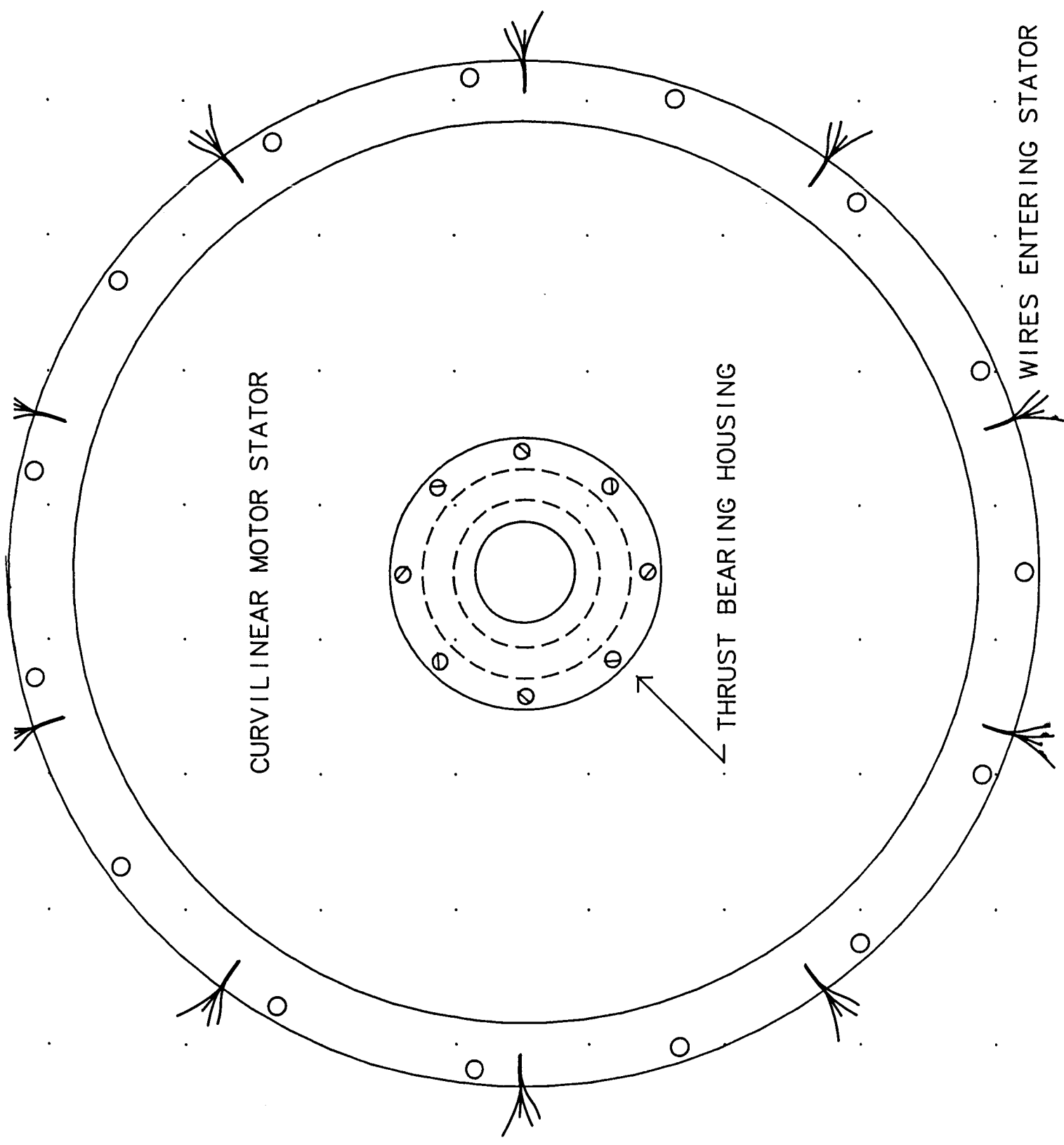


$\frac{1}{2}$ of Stator



Rotor minus shaft.
(spacing between magnets = facewidth of magnet)

FIG 4

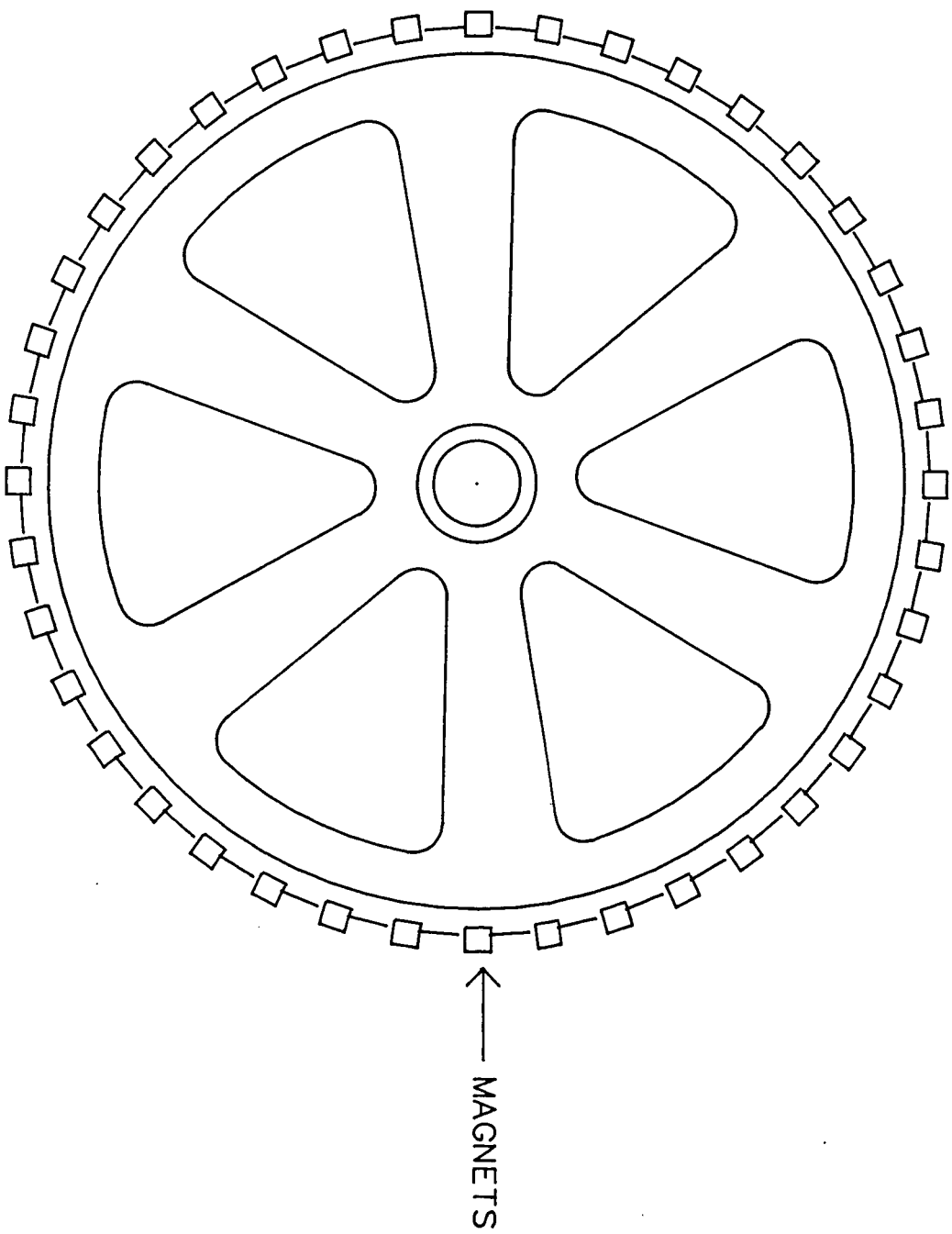


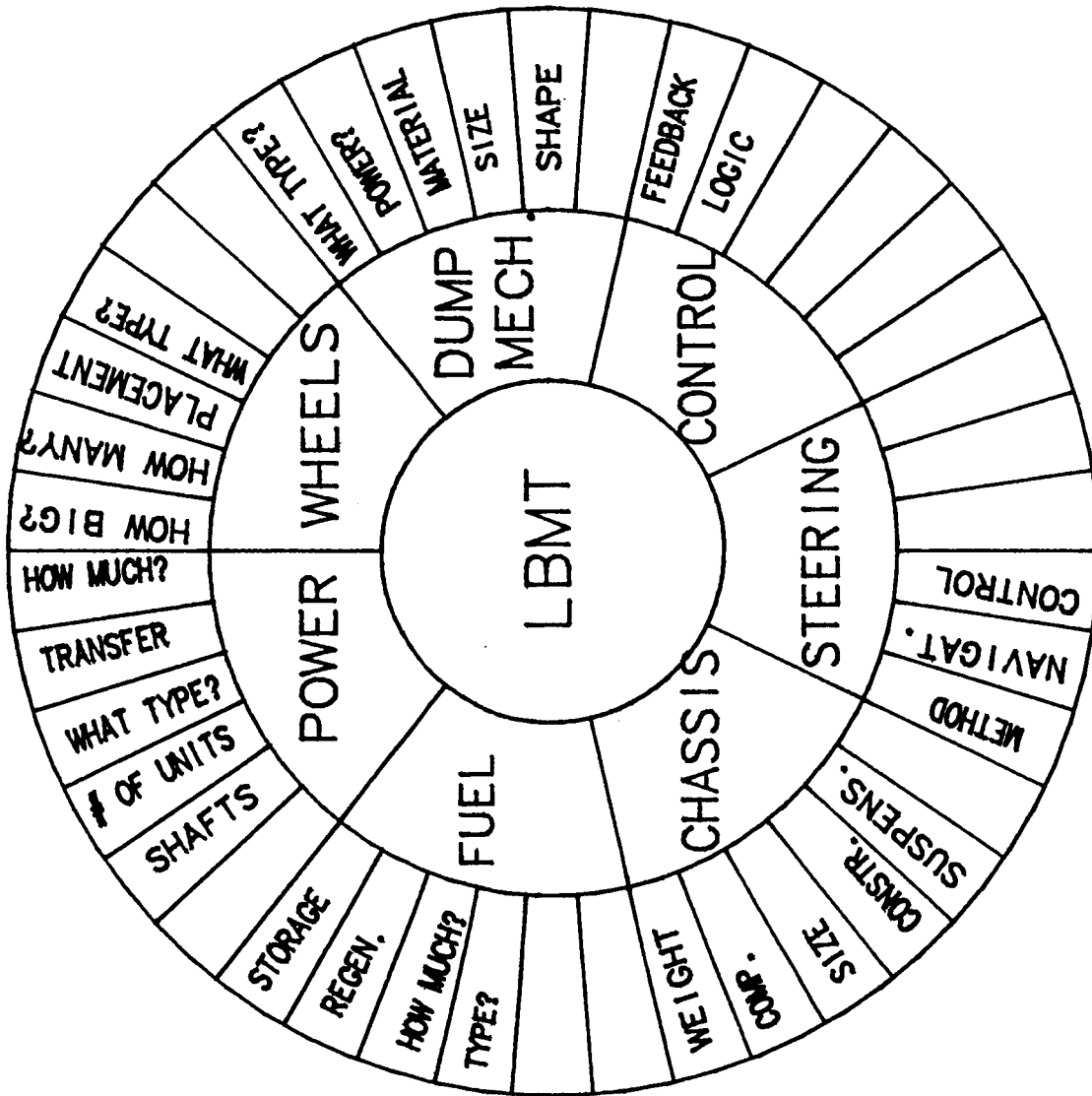
CURVILINEAR MOTOR STATOR

THRUST BEARING HOUSING

WIRES ENTERING STATOR

CURVILINEAR MOTOR ROTOR





Chapter 7

Schematics & Parts List

This chapter contains a list of all parts installed on the Control Module, a parts placement diagram, and a schematic for the module.

7.1 Parts List

All resistors are 0.25 watt, ten percent tolerance, unless otherwise specified. All capacitors are ceramic, 50 volt, twenty percent tolerance, unless otherwise specified.

Integrated Circuits

U1 - 6809
U2 - 28-pin DIP socket
U3 - 28-pin DIP or RAM
U4 - 28-pin DIP or RAM
U5 - 28-pin DIP or RAM
U6 - 6821
U7 - 6821
U8 - 6850
U9 - 6850 or 6852
U10 - PAL10L8
U11 - 1488
U12 - 1489
U13 - 1489
U14 - 4040
U15 - 74LS161 or 74LS163
U16 - 4001
U17 - 4024
U18 - 74LS10

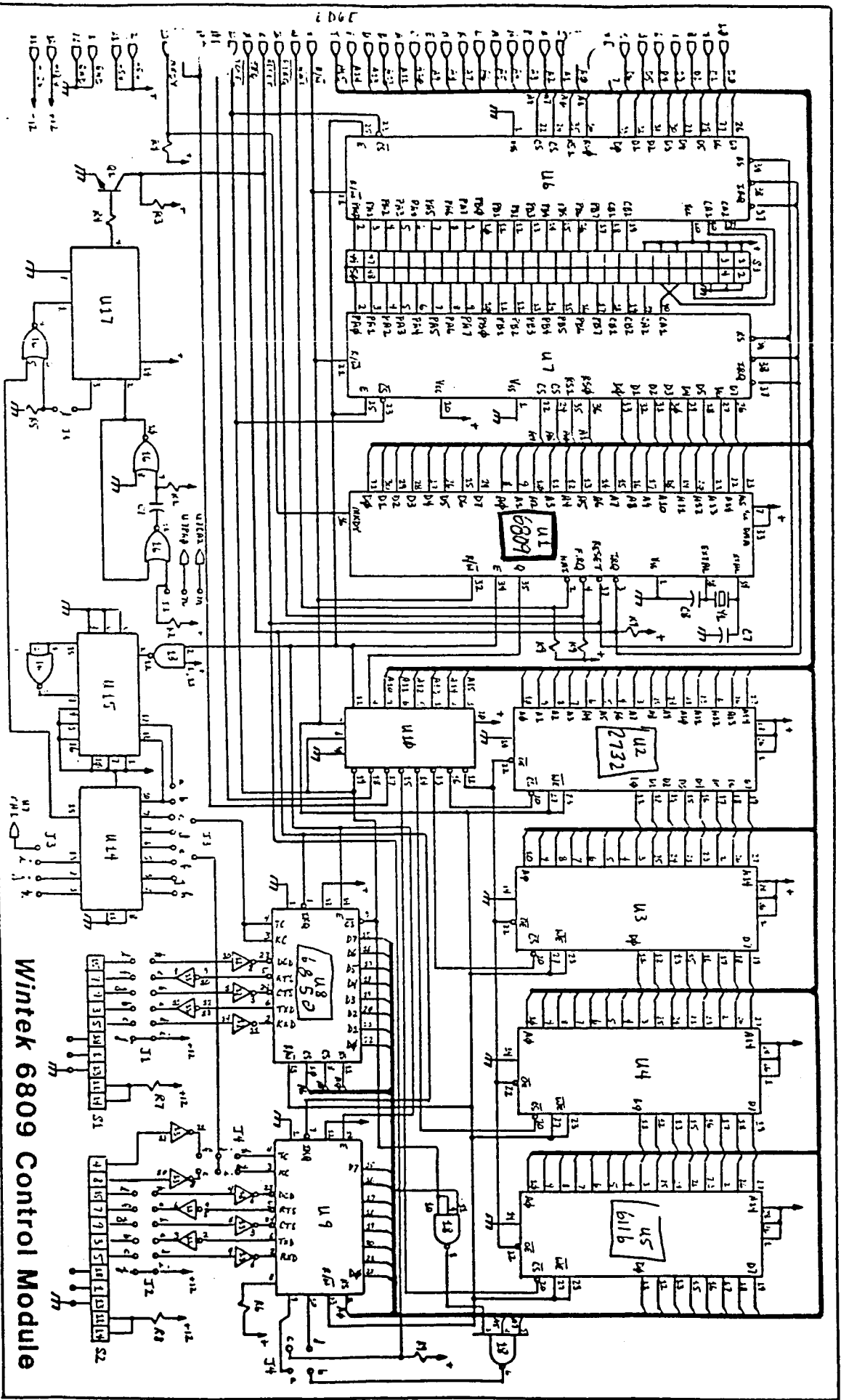
Resistors

R1 - 1M ohm
R2 - 10K ohm
R3 - 10K ohm
R4 - 10K ohm
R5 - 10K ohm
R6 - 10K ohm
R7 - 10K ohm
R8 - 10K ohm
R9 - 4.7K ohm (SIP)

Capacitors

C1 - 4.7 uF 16V tant
C2 - 0.1 uF
C3 - 4.7 uF 16V tant
C4 - 0.1 uF
C5 - 4.7 uF 16V tant
C6 - 0.1 uF
C7 - 24 pF
C8 - 24 pF
C9 - 0.1 uF

Wintek 6809 Control Module
7.1 Schematic



Wintek 6809 Control Module

Wintek 6809 Control Module
7.1 Parts List

XX-42

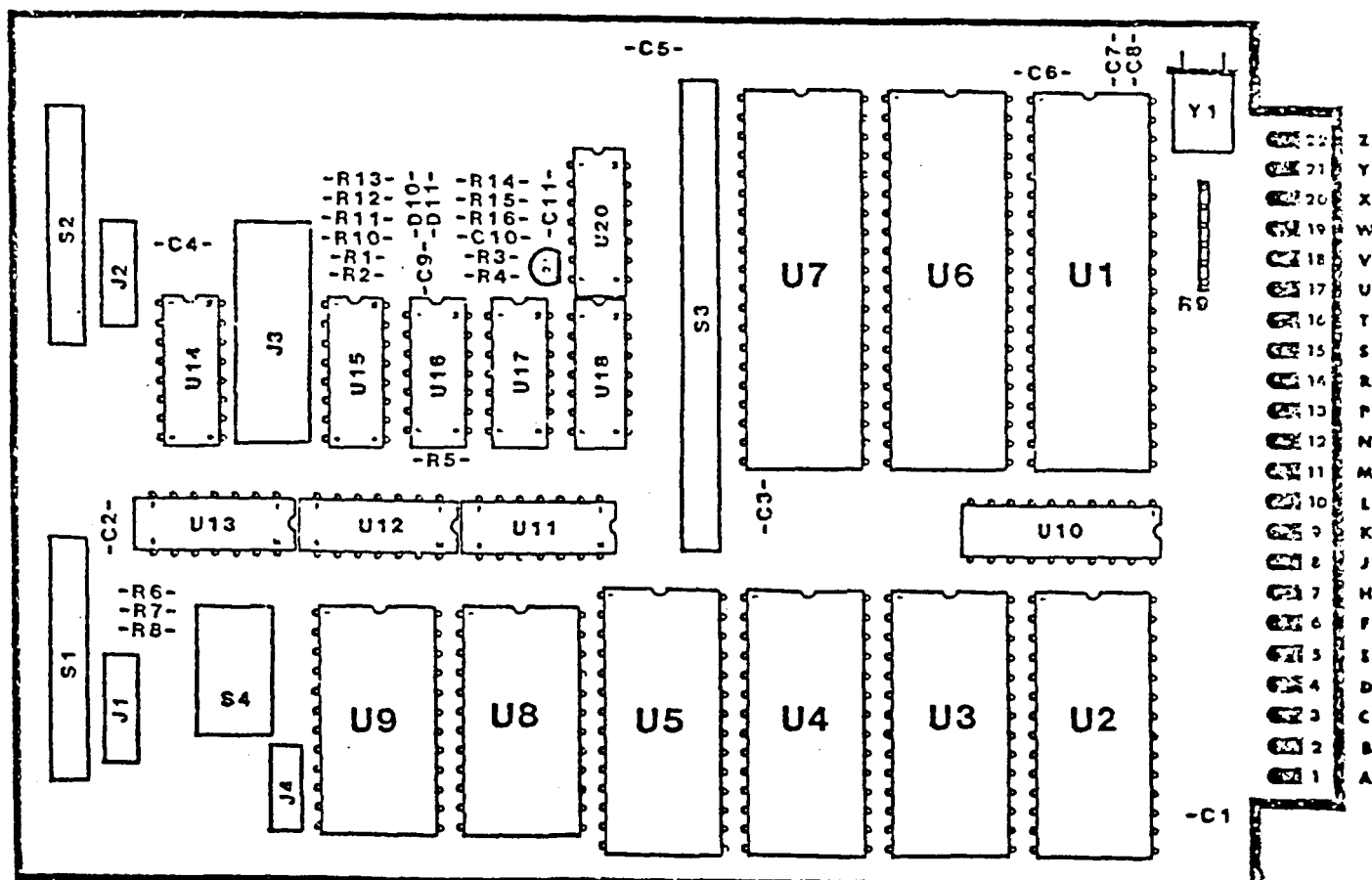
Transistor
Q1 - 2N3903

Crystal
Y1 - 4.0 MHz crystal

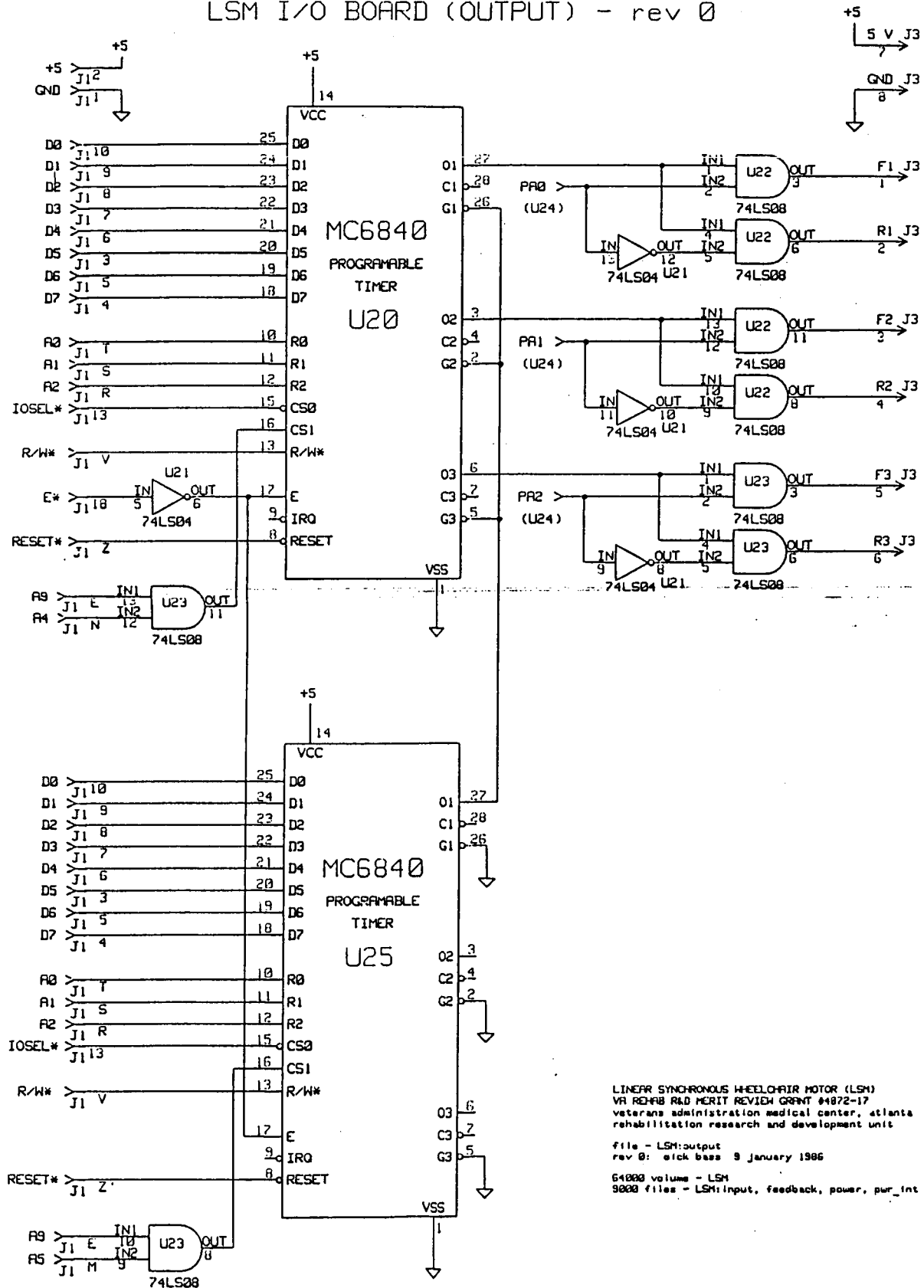
Connectors
S1 - 26-pin header
S2 - 26-pin header
S3 - 50-pin header

Jumper Areas
J1 - 2x6 header
J2 - 2x6 header
J3 - 4x12 header

7.2 Parts Placement



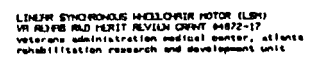
LSM I/O BOARD (OUTPUT) - rev 0



LINEAR SYNCHRONOUS WHEELCHAIR MOTOR (LSM)
VA RENFAS RAD HERIT REVIEW GRANT #4872-17
veterans administration medical center, atlanta
rehabilitation research and development unit

file - LSM:output
rev 0: stick base 9 January 1986

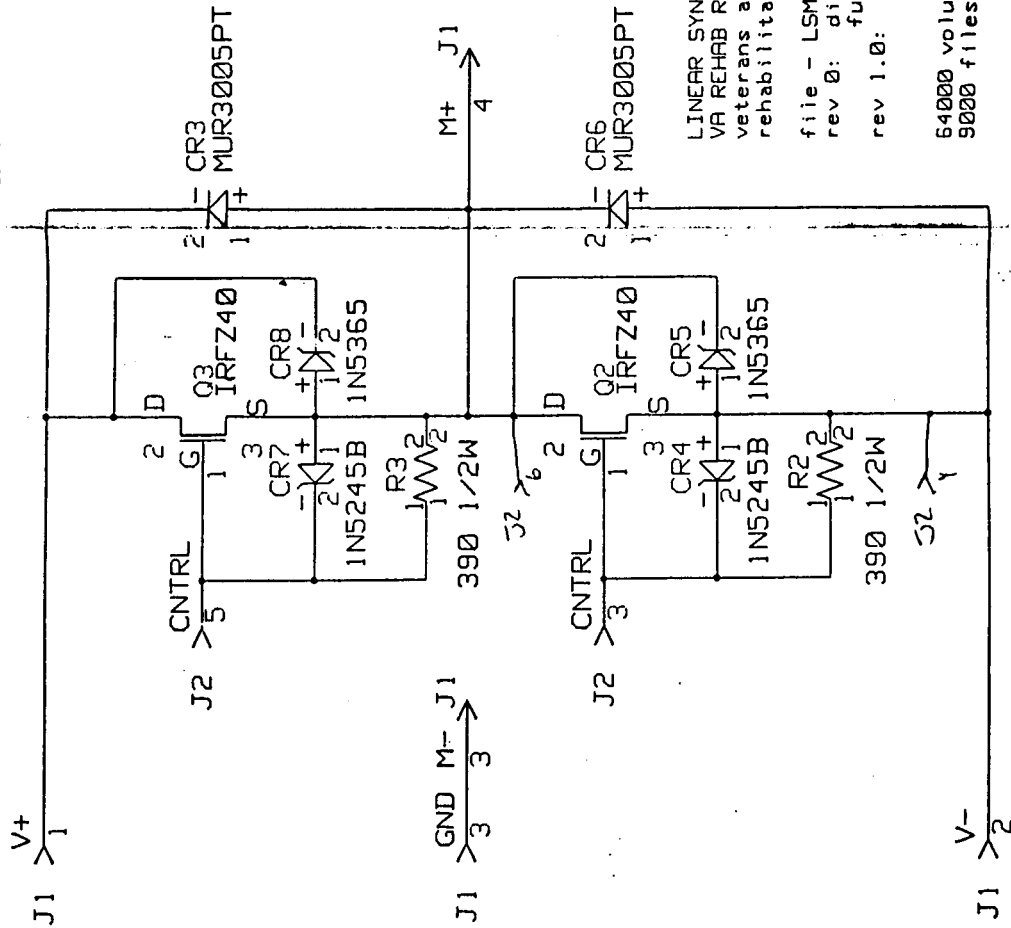
64000 volume - LSM
9000 files - LSM:input, feedback, power, pur_int



File - LSH:pur-int
rev B: cick base 2 January 1968
full-bridge inverter
rev 1.0: cick base 15 May 1968
half-bridge inverter

84800 volume = LPM
96000 files = LPM: output, input, feedback, power

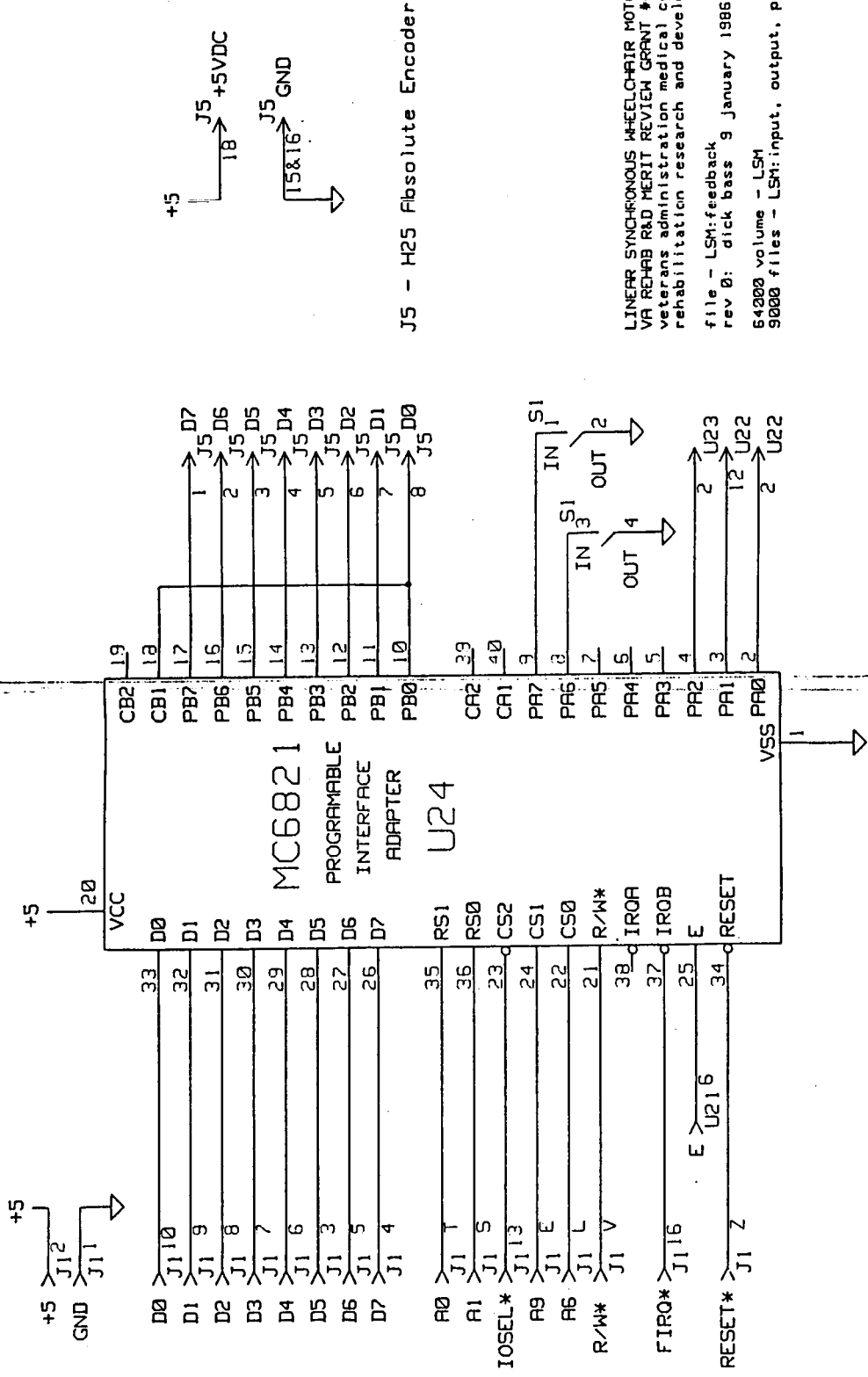
LSM POWER MODULE - rev 1.0



LINEAR SYNCHRONOUS WHEELCHAIR MOTOR (LSM)
 VA REHAB R&D MERIT REVIEW GRANT #4872-17
 veterans administration medical center, atlanta
 rehabilitation research and development unit

file - LSM:power
 rev 0: dick bass 31 december 1985
 rev 1.0: full-bridge inverter
 rev 1.0: dick bass 11 january 1986
 half-bridge inverter
 64000 volume - LSM
 9000 files - LSM:output, input, feedback, pwr_int

LSM I/O BOARD (FEEDBACK) - rev 0



J5 - H25 Absolute Encoder

LINEAR SYNCHRONOUS WHEELCHAIR MOTOR (LSM)
 VA REHAB R&D MERIT REVIEW GRANT #4872-17
 Veterans administration medical center, atlanta
 rehabilitation research and development unit
 file - LSM:feedback
 rev 0: disk bass 9 January 1986
 64000 volume - LSM
 90000 files - LSM:input, output, power, pwr_int

Lunar Dump Truck

(*Lunar Bulk Material Transport*)

William L. Jones

Earl Smith

Erik Green

Since this is the initial report, the progress that has been made to this point is primarily organizational. the items that are already accomplished are;

1. The team has set up two meetings a week. The first meeting is at 7:00 P.M. Monday, where we will discuss the items to be done during the week. The second meeting is at 4:00 P.M. Friday where any new, or pertinent, information gathered during the week will be discussed.
2. The team discussed the problem statement, and brainstormed about what the essential characteristics a lunar dump truck should have. The list generated

by this meeting was narrowed down to what we perceived as the bare minimum, from which a rough draft was written.

3. Finally, we discussed possible avenues of research, and what types of information will be needed to begin the design.

Progress Report

Week 2

1. William L. Jones
2. Earl Smith
3. Erik Green
4. Andy McHenry

October 8, 1987

To date, we have proposed and discussed several preliminary designs for the LBMT, and have a design which we will pursue. For this design, the following areas have been identified as areas where the bulk of the research will be concentrated.

1. Lunar Surface Analysis-- Since the characteristics of the lunar surface will be a factor in the design of the wheels, these characteristics will be researched in order to determine an optimum profile for traction. Also, the typical density

of the lunar regolith will be determined so the size of the transport can be optimized.

2. Suspension Systems-- The initial concept of the transport consists of a scissor-like truss, and since this will be a "heavy lift" vehicle, much of the research will be in this area.
3. Power Systems-- We have determined that the transport will be powered by a fuel cell/ integral electric motor combination, which will be researched as much as possible from existing reference materials. However, some (or most) of the information in this area will come from a Dr. Kent Davey, who is a professor in the electrical engineering department.

Progress Report

Week 3

1. William L. Jones-Researching metal properties and structure
2. Earl Smith-surface studies and wrote progress report
3. Erik Green-researching wheel design
4. Andy McHenry-researching skelton model and power transmission

This week we looked into the suspension design, lunar geology, properties of metals. Because of the discussion at our team meeting on October 15, 1987 we are starting to keep notes of the ideas that we have come up with so we can better answer why we choose the model the we had choose or so the others will know the ideas that we obtained.

The biggest task we undertook was the design of the dumptrunk. Throughout the quarter we have talked about using six wheels to using a lift mechanism (where the truck has four wheels). One worry that was expressed with six wheels was the friction between the wheels. When we thought about four wheels, we then talked about the many ways we could hold the bowl while the dumping takes place.

Another concern that was expressed was where would the motors and fuel system be place and where would our backup system be placed. For right now we decided to make as much

room as possible to put the fuel system, motor, and backup system at the same elevation. However, since we just thought about it, this idea is by no means finalized.

Since we have spent a lot of time on the previous ideas, we have not gone into depth into the robotics and spring mass damping system of our project. Probably the best way for us to research information is to start looking at old class notes on the spring mass damping system then go to the library and research the topic on a larger scale. For the information on robotics, we merely looked through books on the subject in order to help us come up with some more ideas.

Progress Report

Week 4

1. William L. Jones-Learning to use CAD for doing drawings
2. Earl Smith-looked into lubrication and bearings
3. Erik Green-researching wheel design and energy supply; time schedule
4. Andy McHenry-researched motor and power transmission

William L Jones is currently is learning to use the cadkey program in the me department because it does have the ability to do three dimensional views. However, the documentation on this aspect of the program is somewhat unclear. Also is doing the research on the dump mechanism and overall structure of the chassis.

Erik Green is researching wheel design and vehicle energy requirements. Currently we have two choices for the wheel design; mesh wheels or metal hoop wheels. Several choices also exist for the energy supply; conventional battery storage, solar energy, nuclear energy, fuel cells and a flywheel storage system. Most are useless due to size, cost, or other factors. The choice has been narrowed down to either fuel cells, or the flywheel system. Also prepared a time schedule for the remainder of the project.

Earl Smith Is currently looking into possible methods for lubrication of the linkage joints. For this, he is researching different types of bea rings (space, journal, thrust, and sealed) and the low temperature proper ties of some possible lubricants. He is also looking into the soil mechanics of the moon's surface.

Andy McHenry is concerned mainly with the electric motors that will be used on the LBMT. He will be meeting with Dr. Kent Davey on October 23 to discuss the uses and limitations of integral electic motors. Concerning the power requirements of the vehicle, the group is strongly in favor of each wheel having a motor, some or all of which will be used to drive the dump mechanism. Some considerations about the motors are;

1. Power Requirements
2. Output Torque--we need high torque at low rpm
3. Gearing if necessary
4. Dust and dirt contamination
5. Lubrication
6. Life and reliabilty
7. Weight
8. Adaptability to other machines

Progress Report

Week 5

1. William L. Jones-Using CAD and working on structure
2. Earl Smith- Automation, robotics, and lubrication
3. Erik Green- Wheel design and energy supply
4. Andy McHenry- motor and power transmission

William L. Jones- Researching materials to use to construct the truss that will support the bucket. He has narrowed it down to an aluminum or nickel alloy. Certain other alloys such as titanium alloys would probably save more weight in the overall design, but the cost of these alloys is prohibitive. He is also working on the CADKEY system and has found that the 3D capabilities of this system are hard to use. Also, he is working on the kinematics of the dumping mechanism and the truss structure of the vehicle. We feel that a dumping mechanism which incorporates the use of the moon's gravity to help the dump action is preferable.

Erik Green- Erik is concluding the research on the design of the wheels. From his research, we feel that mesh wheels (used for the U.S. Lunar Rover) have more load carrying capability than the metal hoop wheels (used in the Soviet vehicle). They also allow for greater deflection with better traction. Erik is now researching the energy source for the vehicle. We are leaning towards the use of fuel cells because Erik's preliminary research indicates that they operate longer, have a higher output for a given weight, and use conventional gasses for fuels. Also, these fuels can be recovered and used again.

Andrew McHenry- We are still planning to use articulated steering on our vehicle. We will most likely incorporate one motor per wheel. Andy has met with Dr. Kent Davey in Electrical Engineering to discuss his curvilinear motor. A representative model has the following specifications:

1. torque = 30 ft-lbs. at 25 rpm
2. weight = 100 lbs. for a 10" radius
3. power consumption: 360 VA

Earl Smith- He is currently researching automation and robotics. This information will be used in the control systems since we plan on having it controlled internally as well as from earth. In addition, some sort of sensor systems will be required to provide feedback. This feedback will be necessary in the dumping operation, as well as local control and the earth control systems. He is also continuing to research lubrication considerations. Earl plans to meet with Dr. W.O. Winer in Mechanical Engineering.

Progress Report

Week 6

1. William L. Jones-Using CAD and working on structure
2. Earl Smith- Automation, robotics, and lubrication
3. Erik Green- Wheel design and energy supply
4. Andy McHenry- motor and power transmission

William L. Jones- He is wworking on the truss structure of the vehicle,working on the dumping mechanism and learning to use the CADKEY system. Concerning the CADKEY system, he is well along the learning curve, and is begining to produce some exceptional 3-D drawings of some of the proposed designs. As for the truss structure and dumping mechanism, he will be discussing these topics with Dr. Lipkin Friday, November 6.

Erik Green- Erik is now researching the energy source for the vehicle. We are leaning towards the use of fuel cells because Erik's preliminary research indicates that they operate longer,

have a higher output for a given weight, and use conventional gasses for fuels. Also, these fuels can be recovered and used again. Since it appears that the vehicle will have a large power requirement, fuel cells are the logical choice.

Andrew McHenry- He is researching the design factors involved in the design of the integral motors that will be used in the vehicle. However, since actual engineering data is somewhat limited due to the relative newness of integral motors, he is planning to take a trip to the Veterans Administration Hospital in Decatur to look at an/the existing prototype. The people there who are involved with the testing of the motor should be an invaluable source of information.

Earl Smith- He is continuing his research into robotics/automation. Although the vehicle will not need what is normally thought of as "robotics", it will need a fairly large set of sensing instruments, some of which can be broadly grouped under robotics. His research into this area is initially concerned with identifying those sensing instruments which are essential for remote operation of the LBMT.

He is currently researching automation and robotics. This information will be used in the control systems since we plan on having it controlled internally as well as from earth. In addition, some sort of sensor systems will be required to provide feedback. This feedback will be necessary in the dumping operation, as well as local control and the earth control systems. He is also continuing to research lubrication considerations. Earl plans to meet with Dr. W.O. Winer in Mechanical Engineering.

Progress Report

Week 7

1. William L. Jones- dimensions of the dumping linkage
2. Earl Smith- Automation, robotics, and lubrication
3. Erik Green- Wheel design, energy supply, and trade studies
4. Andy McHenry- motor, power transmission, and trade studies

William L. Jones- He came up with approximate dimensions of the linkages used in the dumping mechanism. He is going to analyze this linkage design on CATIA system, which can analyze the positional kinematics of the dump. He will be working with Earl on the digital aspects of the vehicle controls.

Erik Green- Erik is continuing his research on the energy source for the vehicle. We are learning the use of fuel cells because Erik's preliminary research indicates that they operate longer, have a higher output for a given weight, and uses conventional gasses for fuels. Also,

these fuels can be recovered and used again. Since it appears that the vehicle will have a large power requirement, fuel cells are the logical choice. Also, he is putting together graphs for the trade studies.

Andrew McHenry- He is researching the design factors involved in the design of the integral motors that will be used in the vehicle. He is planning to take a trip to the Veterans a trip to the Veteran's Administration Hospital in Decatur on Friday, November 13, 1987 to discuss the existing prototype. From this information we will utilize trade studies to determine the best size motor to use. He will also be looking at vendor catalogues for the proper thrust bearings to use in the motor assembly.

Earl Smith-

He is currently researching automation and robotics. This information will be used in the control systems since we plan on having it controlled internally as well as from earth. In addition, some sort of sensor systems will be required to provide feedback. This feedback will be necessary in the dumping operation, as well as local control and the earth control systems. He is also continuing to research lubrication considerations. Earl plans to meet with Dr. W.O. Winer in Mechanical Engineering. Also, he is familiarizing himself with the CADKEY system.

Progress Report

Week 8

1. William L. Jones- dimensions of the dumping linkage
2. Earl Smith- Automation, robotics
3. Erik Green- Wheel design, energy supply, and trade studies
4. Andy McHenry- motor prototype design and sizing

William L. Jones- He has written a small computer program that calculates the position of the joints in the linkage throughout the range of motion. Using this program, the following lengths for the links was determined;

bucket link = 4.5 feet

angle link = 3.25 feet with a 2.5 foot arm at an angle
of 45 degrees

lower connecting link = 2.2 feet

upper connecting link = 3.0 feet

Also, I managed to get into this screwball computer from my computer. I should have tried to do this a long time ago. this is something that i am typing so i can see if it will really work. He has also determined the maximum size of the vehicle using the 7.5 foot radius of the shuttle as a limiting factor.

Erik Green- Since we have a maximum size fore the vehicle, he is working on finding the number and size of fuel cells we will need. He has looked in the vendor catalogs for data on fuel cells, but not much is available. He is going to look at the previous reports for more info. He is also continuing to work on the trade studies to see if there are any other limiting factors.

Andrew McHenry- He has met with David Ross at the VA Hospital and examined the existing prototype of Dr. Davey's Curvilinear Motor. There are many changes which will need to be made so that it will be useable on the Lunar Bulk Material Transport. The primary benefit in the use of this motor is its high efficiency. This will be very important in lunar applications since energy is limited and adds weight to the vehicle.

Earl Smith- Since it appears that we won't have very many truly robotic sytems in the design, he is looking more for sensors than anything else. He is also working on the control systems.

Record of Invention No. _____
UTC No. (if applicable) _____

GEORGIA INSTITUTE OF TECHNOLOGY

APPROVAL SHEET (Attach to DISCLOSURE OF INVENTION)

The following questions should be answered by the laboratory or school director, as applicable. The questions are designed to verify the ownership of the invention. This approval should be included when the Invention Disclosure form is submitted to the Office of Technology Transfer.

1. Title of Invention: Lunar Bulk Material Transport

2. List of Inventor(s):

<u>William L. Jones</u>	<u>Earl Smith</u>
<u>Andrew C. McHenry</u>	_____
<u>Erik Green</u>	_____

3. Ownership:

In my opinion this invention:

☒ A. Is owned by the Institute in accordance with the Patent Policy.

☐ B. Was developed by the inventor(s) without use of Institute time, facilities or materials, and is not related to the inventor's area of technical responsibility to the Institute and hence belongs to the inventor(s).

4. Research project advisor approval for student submissions (if applicable):

_____	_____
Advisor	Date

Reviewed for Institute ownership by laboratory or school director.

_____	_____
Name	Date

Title/Unit

GEORGIA INSTITUTE OF TECHNOLOGY
DISCLOSURE OF INVENTION

Submit this disclosure to the Office of Technology Transfer (OTT) or contact that office for assistance. Disclosure must contain the following items: (1) title of invention, (2) a complete statement of invention and suggested scope, (3) results demonstrating that the concept is valid, (4) variations and alternate forms of the invention, (5) a statement of the novel features of the invention and how these features distinguish your invention from the state of the art as known to you, (6) applications of the technology, and (7) supporting information.

1. Title

Technical Title: Lunar Bulk Material Transport

Layman's Title (34 characters maximum, including spaces): Lunar
Dump Truck

Inventor(s): (Correspondence, patent questions, etc. will be directed to the first named inventor).

A. Signature ~~William L. Jones~~ Revenue Share% _____ Date 12/2/87

Printed Name William L. Jones Citizenship US
First Middle Last

Home Address 599 Cambridge Dr

City Marietta County Cobb State Ga Zip Code 30066

Campus Unit/Mail Address Bx 35214 Campus Phone _____

B. Signature Andrew C. McHenry Revenue Share% _____ Date 12/3/87

Printed Name Andrew Charles McHenry Citizenship USA
First Middle Last

Home Address 5 Spring Mill La

City Haverford County Delaware State PA Zip Code 19041

Campus Unit/Mail Address Box 30382 Campus Phone 875-7317

C. Signature Earl B. Smith Revenue Share% _____ Date 12-3-87

Printed Name EARL BARNETT SMITH Citizenship USA
First Middle Last

Home Address 2883 MEADOW LAKE COURT

City BUFORD County GWINNETT State GA Zip Code 30518

Campus Unit/Mail Address P.O. Box 32086 Campus Phone N/A

DISCLOSURE OF INVENTION

2. Statement of Invention:

Give a complete description of the invention. If necessary, use additional pages, drawings, diagrams, etc. Description may be by reference to a separate document (copy of a report, a preprint, grant application, or the like) attached hereto. If so, identify the document positively. The description should include the best mode that you presently contemplate for making (the apparatus or material invented) or for carrying out the process invented.

Inventor(s) William L Jones Date 12/3/87
Andrew C McHenry Date 12/3/87
Erik Green Date 12/3/87
Earl Smith 12/3/87
Witness* _____ Date _____
_____ Date _____

*The witness should be technically competent and understand the invention.

DISCLOSURE OF INVENTION

3. Results Demonstrating the Concept is Valid:

Cite specific results to date. Indicate whether you have completed preliminary research, laboratory model, or prototype testing.

just preliminary research completed and basic lab model.

4. Variations and Alternative Forms of the Invention:

State all of the alternate forms envisioned to be within the full scope of the invention. List all potential applications and forms of the invention, whether currently proven or not. (For example, chemical inventions should consider all derivatives, analogues, etc.) Be speculative in answering this section. Indicate what testing, if any, you have conducted on these alternate forms.

None

Inventor(s) _____ Date _____

_____ Date _____

_____ Date _____

Witness* _____ Date _____

(printed name)

_____ Date _____

(printed name)

DISCLOSURE OF INVENTION

5. Novel Features:

a. Specify the novel features of your invention. How does the invention differ from present technology?

b. What deficiencies or limitations in the present technology does your invention overcome?

c. Have you or an associate searched the scientific literature with respect to this invention? Yes _____ No ☒. Have you done a patent search? Yes _____ No ☒. If yes in either case, or both, indicate what pertinent information you found and enclose copies if available. Also indicate any other art you are aware of (whatever the source of your information) that is pertinent to your invention. Enclose copies of descriptions if available. (Note: An inventor is under duty by law to disclose to the U.S. Patent and Trademark Office any prior art known to him or her.)

Inventor(s) _____ Date _____

_____ Date _____

_____ Date _____

Witness _____ Date _____

(printed name)

_____ Date _____

(printed name)

DISCLOSURE OF INVENTION

6. Application of the Technology:

List all products you envision resulting from this invention. For each, indicate whether the product could be developed in the near term (less than 2 years) or would require long-term development (more than 2 years).

Inventor(s) _____ Date _____

Date _____

Date _____

Witness _____ Date _____

(printed name)

Date _____

(printed name)

DISCLOSURE OF INVENTION
SUPPORTING INFORMATION

1. Are there publications such as theses, reports, preprints, reprints, etc. pertaining to the invention? Please list with publication dates. Include manuscripts (submitted or not), news releases, feature articles and items from internal publications. Supply copies if possible.

2. On what date was the invention first conceived? Dec Is this date documented? NG Where? _____ Are laboratory records and data available? Give reference numbers and physical location, but do not enclose.

3. Give date, place, and circumstances of any disclosure. If disclosed to specific individuals, give names and dates.

4. Was the work that led to the invention sponsored by an entity external to Georgia Institute of Technology? Yes _____ No _____
 - a) If yes, has sponsor been notified? Yes _____ No _____
 - b) Sponsor Names: _____ GIT Project Nos. _____

5. What firms do you think may be interested, in the invention and why. Name specific persons within the companies if possible.

DISCLOSURE OF INVENTION
SUPPORTING INFORMATION

6. Setting aside your personal interest, what do you see as the greatest obstacles to the adoption of your invention?

7. Alternate Technology and Competition:

- a. Describe alternate technologies of which you are aware that accomplish the purpose of the invention.
- b. List the companies and their products currently on the market which make use of these alternate technologies.
- c. List any research groups currently engaged in research and development in this area.

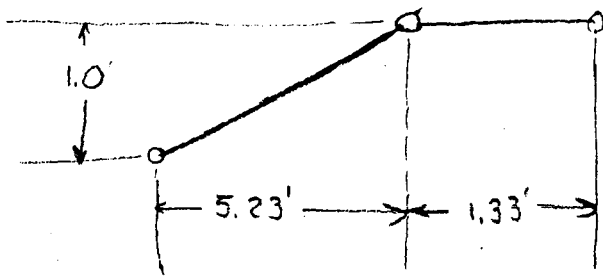
8. Future Research Plans:

- a. What additional research is needed to complete development and testing of the invention? What time frame and estimated budget is needed for the completion of each step?
- b. Is this additional research presently being undertaken? Yes ___ No ___
- c. If yes, under whose sponsorship?
- d. If no, should corporate sponsorship be pursued? Yes ___ No ___

Suggested corporation(s) _____

9. Attach, sign and date additional sheets if necessary. Enclose sketches, drawings, photographs and other materials that help illustrate the description. (Rough artwork, flow sheets, Polaroid photographs and penciled graphs are satisfactory as long as they tell a clear and understandable story.)

SAMPLE CALCULATIONS of the Two Bar Mechanism



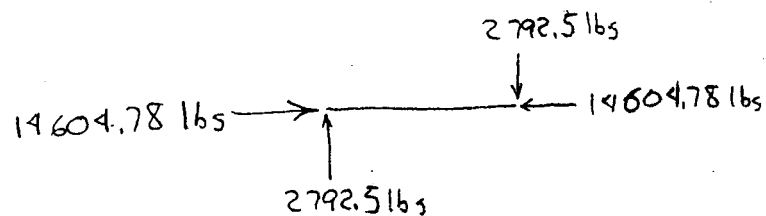
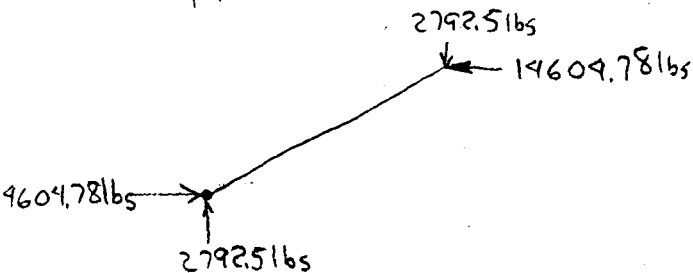
$$\sum M_A = -5.23(F_1) + 1.0(F_2) = 0$$

$$1.0 F_2 = 5.23(2792.5)$$

$$F_2 = 14604.78$$

$$F_1 = 2792.5$$

FREE BODY DIAGRAMS



If the bars are made out an aluminum alloy.

The aluminum alloy with the maximum yield strength is 2011-T8 with $S_y = 45$ Kpsi. The force in the longest bar is $F = 14869.4$ lbs. So for the smallest diameter where plastic deformation would not occur, we have the follow calculations:

$$\frac{14869}{A} = 45000; A = \frac{\pi d^2}{4} = 0.3304 \text{ in}^2$$

$$d^2 = \frac{4(0.3304)}{\pi} = 0.4207 \text{ in}^2; d = 0.6486 \text{ in}$$

For the shortest bar:

$$F = 14604.78 \text{ lbs.}$$

$$\frac{14604.78}{A} = 45000; A = \frac{\pi d^2}{4} = 0.3246$$

$$d^2 = \frac{4(0.3246)}{\pi} = 0.413 \text{ in}^2; d = 0.6428 \text{ in}$$

SAMPLE CALCULATIONS of the Two Bar Mechanism (con.)

If the bar is made out of a carbon steel alloy

The alloy with the maximum yield strength is 6150 (Hot Rolled, annealed 1" Rd 0.1 Q 1550 F Drawn 1000 F) and has a value of 170,000 Psi

Calculation of longest bar:

$$F = 141869.4 \text{ lbs}$$

$$\frac{141869.4}{A} = 170000 ; A = \frac{\pi d^2}{4} = 0.212$$

$$d^2 = \frac{4(0.212)}{\pi} = 0.270 ; d = 0.5201 \text{ in}$$

For the shorter bar:

$$F = 14604.78 \text{ lbs}$$

$$\frac{14604.78}{A} = 170,000 ; A = \frac{\pi d^2}{4} = 0.0859 \text{ in}$$

$$d^2 = \frac{4(0.0859)}{\pi} = 0.1091 \text{ in}^2 ; d = 0.331 \text{ in}$$

SAMPLE CALCULATIONS
of some spring materials

Music Wire

$$S_{UT} = \frac{A}{d^m} \quad A = 196 \text{ Kpsi} ; m = .146 ; d = 0.004 \text{ in}$$

$$S_{UT} = \frac{196 \times 10^3}{0.004^{.146}} = 3223.12 \text{ psi} = 32.23 \times 10^3 \text{ Kpsi}$$

Distortion Energy Theory

$$S_y = 0.577 S_{UT} \\ = 0.577 (32.23 \times 10^3) = 1.8597 \times 10^4 \text{ psi}$$

O.1 tempered wire

$$S_{UT} = \frac{A}{d^m} \quad A = 149 \text{ Kpsi} ; m = 0.186 ; d = 0.500 \text{ in}$$

$$S_{UT} = \frac{149 \times 10^3 \text{ Kpsi}}{0.500^{.186}} = 169.503 \text{ Kpsi}$$

Distortion Energy Theory

$$S_y = 0.577 S_{UT} \\ = 0.577 (169.503 \times 10^3) = 97.803 \times 10^3 \text{ psi}$$

Hard - drawn wire

$$S_{UT} = \frac{A}{d^m} \quad A = 136 \text{ Kpsi} ; m = 0.192 ; d = 0.500$$

$$S_{UT} = \frac{136 \times 10^3}{0.500^{.192}} = 155.36 \text{ Kpsi}$$

Distortion Energy Theory

$$S_y = 0.577 S_{UT} \\ = 0.577 (155.36 \times 10^3) = 89.643 \times 10^3 \text{ psi}$$

Chrome vanadium

$$S_{UT} = \frac{A}{d^m} \quad A = 169 \text{ Kpsi} ; m = 0.167 ; d = 0.437$$

$$S_{UT} = \frac{169 \times 10^3}{.437^{.167}} = 144.193 \text{ Kpsi}$$

Distortion Energy Theory

$$S_y = 0.577 S_{UT} \\ = 0.577 (144.193 \times 10^3) = 83.199 \times 10^3 \text{ psi}$$

SAMPLE CALCULATIONS
of some spring materials(con.)

Chrome silicon

$$S_{UT} = \frac{A}{d^m}; \quad A = 202 \times 10^3 \text{ psi}; \quad m = 0.112; \quad d = 0.375 \text{ in}$$

$$S_{UT} = \frac{202 \times 10^3}{0.375^{0.112}} = 225.454 \times 10^3 \text{ Kpsi}$$

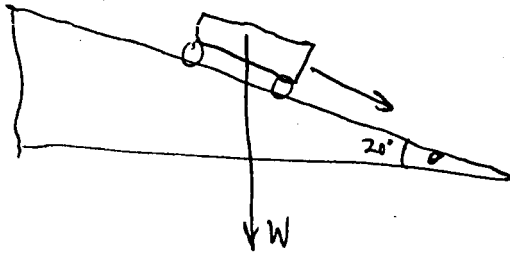
Distortion Energy Theory

$$S_y = 0.577 S_{sy}$$

$$= 0.577 (225.454 \times 10^3) = 130.087 \times 10^3 \text{ Kpsi}$$

Torque Calculations

$W \equiv$ weight of vehicle, fully loaded on moon



$$F = W \sin \theta$$

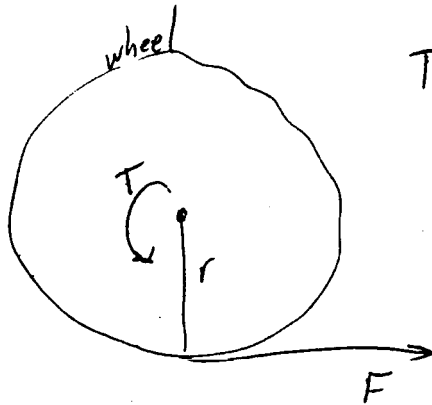
$$F = 7500 \sin(20)$$

$$F = 2565 \text{ lb.}$$

$$T = r \times F$$

$$= 2.9 \times (2565)$$

$$T = 7438.5 \text{ ft-lb.}$$



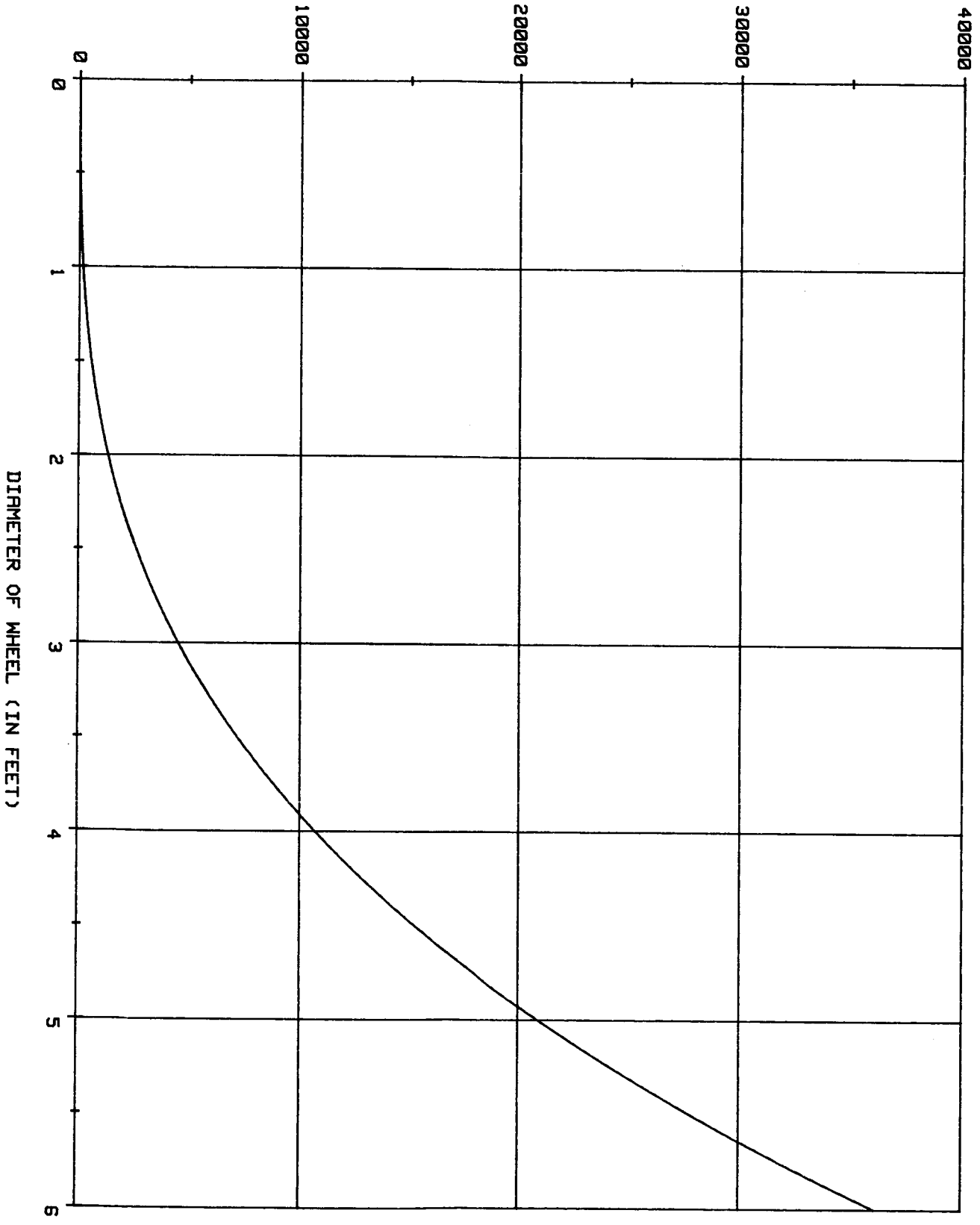
4 wheeled vehicle

$$\frac{F}{4} = F_{\text{wheel}}$$

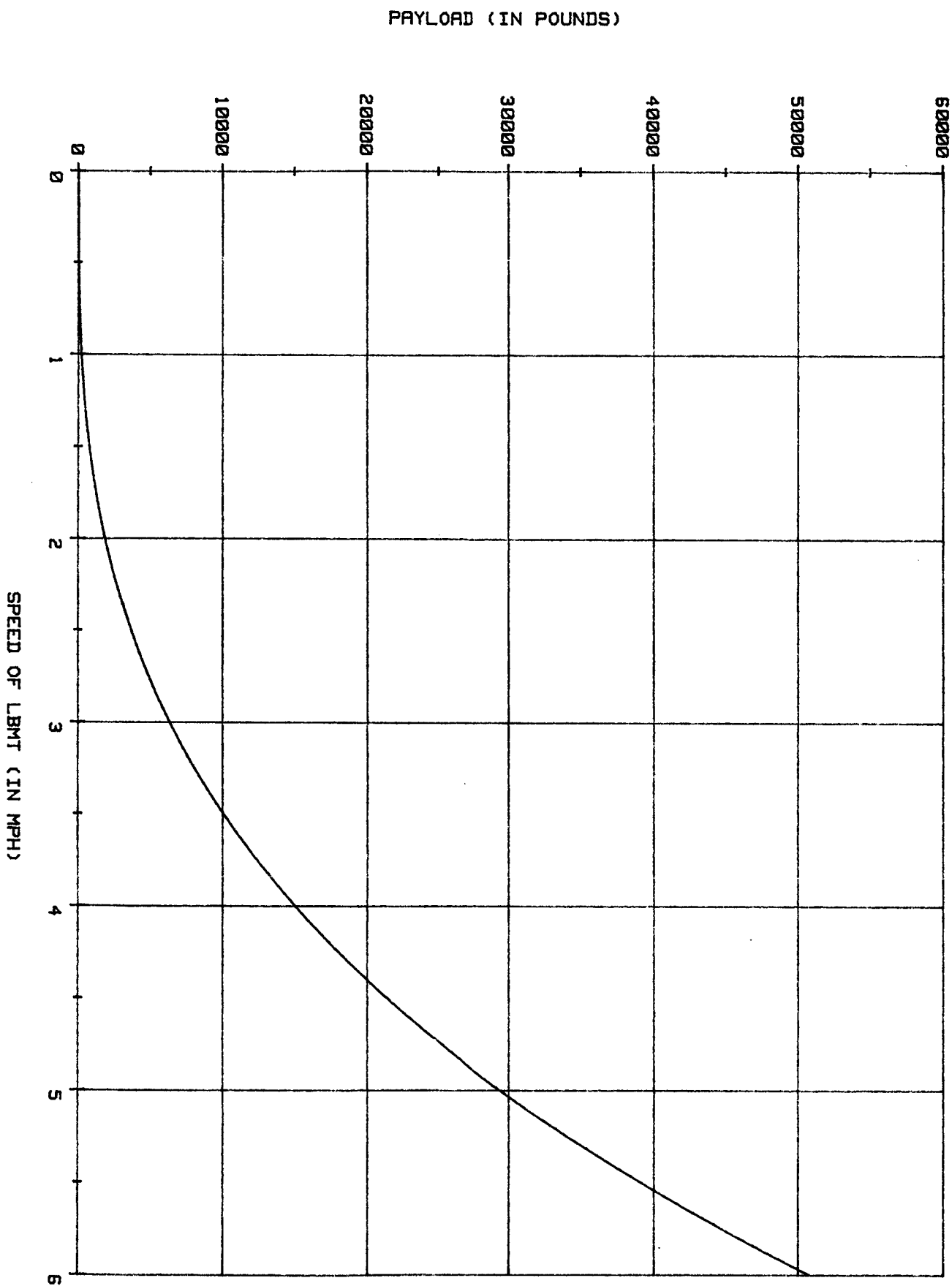
$$\frac{T}{4} = T_{\text{wheel}} = 1860 \text{ ft-lb}$$

PAYLOAD (IN POUNDS) *Field Height*

PAYLOAD VS. DIAMETER OF WHEEL

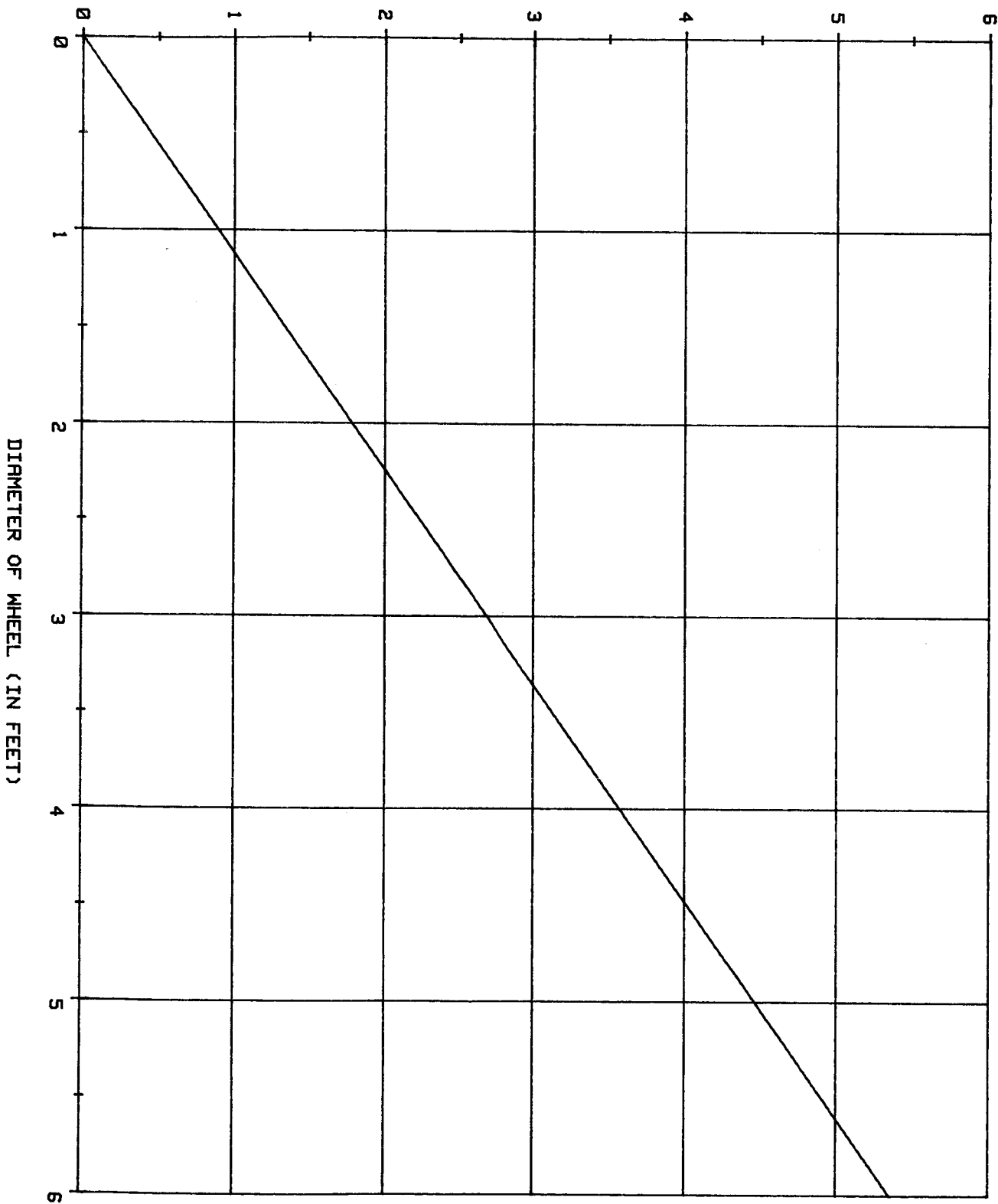


PAYLOAD VS. SPEED OF LBMT



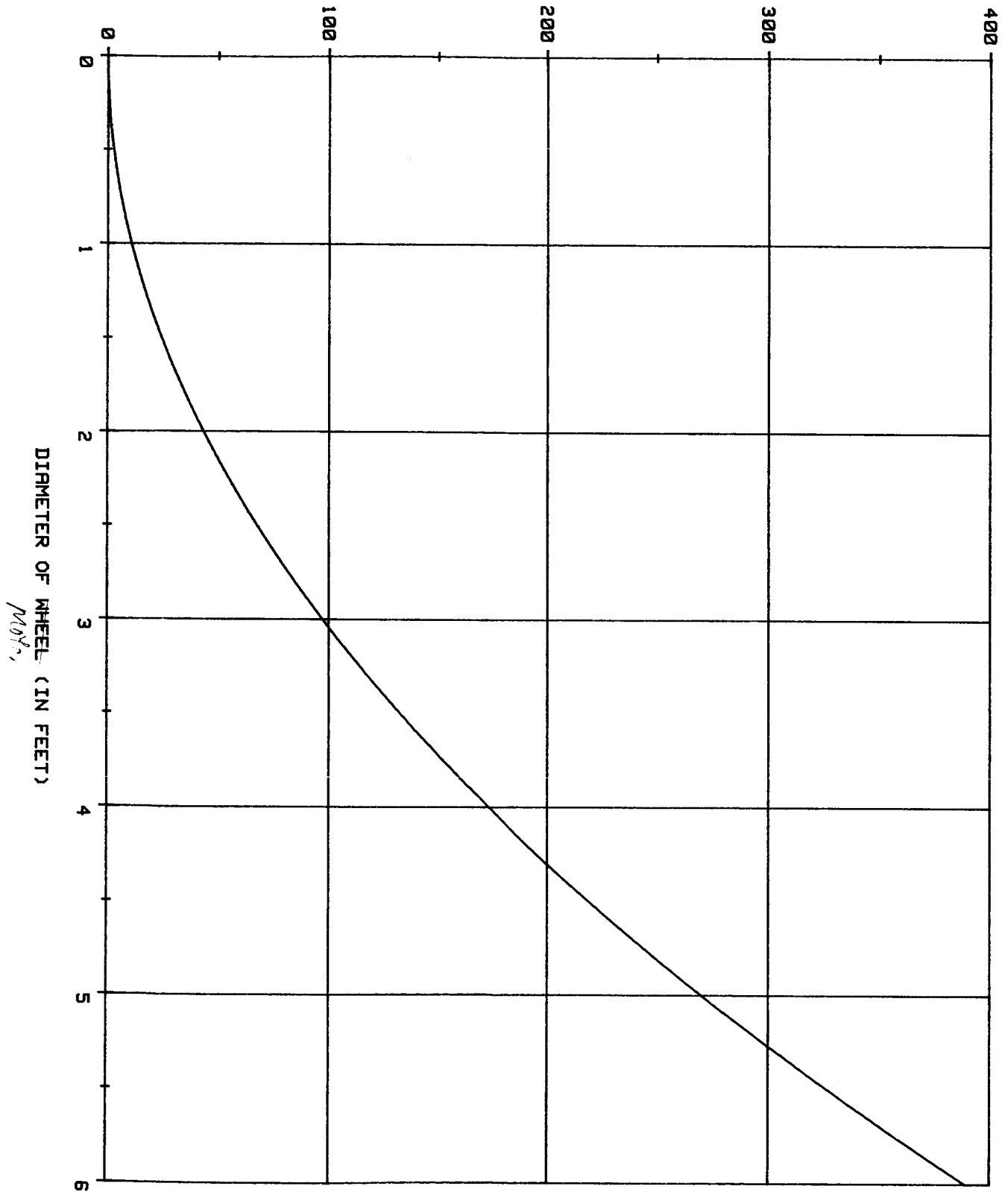
SPEED OF LBMT (IN MPH)

SPEED OF LBMT VS. DIAMETER OF WHEEL (AT 25 RPM)



TORQUE OF MOTOR (IN FT-LBS)

TORQUE VS. DIAMETER OF WHEEL *Motor*



CURRENT NEEDED (IN AMPS)

CURRENT NEEDED VS. DIAMETER OF WHEEL *Notes*

